Bigger bugs in BART?

Six months in partial service have raised questions about BART’s automation and its safety features

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When we prepared the three-part series on the Bay Area Rapid Transit System (BART), the system had not yet been opened for limited revenue service from Oakland to Fremont. Thus, before the inaugural day, September 11, 1972, we could only report on what the sophisticated and complex automatic train control (ATC) system, and other equipment and components, were supposed to do. It was only after a backlog of operating experience that we and the general public discovered what some of the actual capabilities—and deficiencies—were.

In all candor, however, we did receive a forewarning (following the publication of Part I) from Hodger Hjortsvang, a former systems engineer with BART, that all was not well with the ATC. His letter, and a rebuttal to it from W. A. Bugge of Parsons Brinckerhoff-Tudor-Bechtel (PB&TB), the prime contractors and consultants to BARTD, were published on pp. 16-17 of the December 1972 issue of IEEE Spectrum.

Last stop: a sandpit

On October 2 of last year, a southbound BART train operating under the computer-controlled ATC overshot the Fremont terminal and plowed the lead car onto a sand embankment. The train’s “attendant” (BART’s term for train operator, or its “sometimes” motorman) barely managed to override the ATC manually before impact. In those final desperate seconds he may have realized that no deus ex machina would come to his aid and that all remaining divinity lay within himself. Fortunately, there were no fatalities or even serious injuries as the result of this incident. Although most of the passengers were just “shook up,” the repercussions of that accident are a continuing subject of heated debate.

At the time, David G. Hammond, BART’s assistant general manager and chief engineer, told us that the cause of the accident was...

...A malfunction of a crystal oscillator on board the lead car...This oscillator controlled the commands for a 27 mi/h (43.5 km/h) speed which was the (speed) zone in which the train was approaching the Fremont Station. Examination and detailed tests showed that there was an intermittent short in the crystal oscillator due to its mounting within its case which caused the oscillator to give an incorrect signal. Various tests showed that this ranged between 40 and 70 mi/h (64 to 112 km/h) instead of the correct speed of 27 mi/h...It was further verified by X-ray examination, which showed that an intermittent short was possible because the crystal was in the proper location within its case...

The gist of this explanation was carried in “Special Lines,” in the November 1972 issue of Spectrum. (We shall pursue Hammond’s reply later in this piece.)

The state hearings and report documents

According to a memorandum to “Bechtel Senior Management” from the San Francisco office of Bechtel Incorporated (one of the principals in the PB&TB joint venture), dated November 27, 1972, events leading up to the State of California Senate Public Utilities and Corporations Committee hearings—concerning during that month—had their origins in 1971 (or earlier), when several BARTD engineering employees were dismissed after publicly objecting to certain BART policies. Subsequently, the Walnut Creek Chapter of the California Society of Professional Engineers backed this dissident group, drew up a bill of particulars, and submitted it to the San Francisco legislature. Neatly convened the 16 legislative representatives of BARTD and requested an investigation of BART’s operations by the state’s legislative analyst, Alan Pott.

The Post report. Post report, released on November 9, consists of 106 pages of comments (leading to 31 recommendations), which, in essence, alleged that BART was unsafe as it was being operated as of that date. The two principal stipulations of the report were that...

PB&TB and BARTD allowed BART’s service to begin last September without adequate checks and with train-control deficiencies that jeopardize public safety.

PB&TB overcharged BART for the system engineering and construction-management services rendered.

According to Pott, every statement in his report is based on information from BART, PB&TB, and Westinghouse sources—plus opinions of outside technical consultants. His report emphasizes that the ATC is the key to passenger safety. In this context, the document stresses that BART selected an untested Westinghouse system on the basis that the company presented the lowest bid and because it offered the most advanced circuitry as a spinoff of the missile industry. Further, the report alleges that, prior to the award of the $36 million contract (additional costs have raised the total bid to about $35 million), the California Public Utilities Commission (CPUC) informed BART that previous experience of ATC bidders should be taken into account before the award of contracts. Nevertheless, it is contended in the Post report that BARTD accepted the proposal of the lowest bidder without requiring prior demonstration of the system before giving the go-ahead for final design and installation. Post’s investigative team also visited the Fremont Station incident, and recommended that, because the crystal oscillators may transmit erroneous commands, the speed-control element should be redesigned. The report states in this context: “Contrary to the public position of BART and PB&TB, all evidence available to us indicates that the speed-control circuits on all transit cars...do not possess required fail-safe features and have not been adequately qualified for reasonable assurance of passenger safety.”

The report explains why the present system is unsafe.

Signals are transmitted through a low-power circuit in the tracks. But when there is rust or dirt on the track, the presence of a train may not be detected. When this occurs, protection circuits do not take the necessary action to slow other trains and thereby avoid a collision. (In a later section, we will discuss the remedial measures taken by BART to eliminate this defect.)

The report also warns that the present system in involving the use of personal relaying information by telephone is not foolproof and claims that, on two occasions, communications errors have placed two trains within the same block.

This method was called “only slightly more sophis-
Summary of the Battlette Institute report

Scope: The work conducted in this study consisted of a limited number of tests to determine the operation of the automatic train protection system and the vehicle system portions of the BART ATO system...

The analysis was concerned with the use of a methodology and safety criteria... to reduce the possibility of false indications and false alarms. Analysis... was limited to considerations of the effect on safety of single-component malfunctions...

In preliminary analyses of the systems, particular subsystems were identified as being individually involved in the system. However, when other subsystems were analyzed, they were identified as being involved in the system in any way. As a result, they were analyzed further in greater detail under both normal and malfunction operating conditions to determine if they should be identified that would result in a condition that would be either unsafe or potentially unsafe. In other cases, an... analyst was made of the failure rate of those components identified that analyses whose failure might result in an unsafe condition.

Results: Under the condition of all subsystems operating normally (i.e., no malfunctions, no conditions found), the systems were either in the analysis conditions.

With respect to the Post report's criticism, the report states that BARTB accepted a contract for design and maintenance of the system. This contract was... provided full automatic systems. This is because BARTB should have been able to do the same thing for the overall Bart project. BARTB claims, however, that a 13 percent fee is normal, is in accordance with the ASCER manual, and compares favorably with other public projects 'of similar magnitude and complexity.'

BARTD, the Bay Area Rapid Transit District, on the other hand, has a different perspective. BARTD claims that BARTB was meeting the need for a viable operating system. The report states that BARTB's performance was... a year a number of things have occurred which have not engendered a feeling of confidence toward top management of the system. In December 1971, there was a collision wherein a moving train struck a stopped train. At a board meeting, the directors were presented with the final report of the BARTB investigation. The report was... presented to the board... At the meeting, the Board of Inquiry was never reconvened. Also, to December 1972, the Chief Engineer of BARTD was asked specifically whether or not there were any serious problems with the ATO. He responded that there were a few "bumps..." but that there were no serious problems. This statement was made after the September 1971 Battlette Institute report which pointed out the train-detection problem.

In January 1972, three BARTD engineers approved the one- and other dimensions that are now under the reliability of the ATO system and the need to involve lower-level staff more in the... the testing phase of their work. The system was... the ATO problem was not identified by the Board of Inquiry. However, in the past year... the Board of Inquiry never reconvened. Also, in December 1972, the Chief Engineer of BARTD was asked specifically whether or not there were any serious problems with the ATO. He responded that there were a few "bumps..." but that there were no serious problems. This statement was made after the September 1971 Battlette Institute report which pointed out the train-detection problem.

Although fail-safe circuits are used in some subsystems of the vehicle system, redundant circuits play a large role in performing safety functions. Analysis of these redundant circuits indicates that they have their intended function in a safe manner if only a single malfunction at a given time is considered. However, multiple malfunctions were identified that should occur simultaneously, a potentially unsafe condition.

Conclusions. The conclusions that can be drawn as the result of the limited safety analysis of the BART ATO system are:

1. Under normal conditions, the system appears to operate in a safe manner that is not unsafe.

2. Under conditions of single malfunctions (not multiple) no clearly defined unsafe operating condition was identified. However, circuit conditions were identified that, should they occur, a potentially unsafe condition may result.

3. The operating safety of the vehicle system depends upon redundant operation of fail-safe circuits and fail-safe circuits in these circuits may result in unsafe operating conditions.

Recommends. As a result of the... analysis of the BART ATO system it is recommended that:

- Further investigation be made concerning the immunity of the subsystems to the potentially... unsafe condition condition. It may result.

- A more detailed safety analysis be made of the vehicle system, with an emphasis on the propulsion-traction portion of the system that was possible in this limited analysis.

Complaints of a BART director

Daniel C. Helix, mayor of Concord, Calif., has been a BARTD director since November 1971. The following are excerpts from a letter he wrote to the Contra Costa Mayors' Conference on January 4, 1972.

I am writing this letter with the morose lock system used as backup for train separation. On occasion, manual operation of trains through certain stretches has been required... indeed, there was no train; manual operation has also been used... code. According to BARTD, these malfunctions continue... make it more than 95 percent of the time.

Further, presently scheduled 10-minute train headways... time between stations. Also, the automatic train operation (ATO) is steadily improving, with "false train occupancies... decrease to the point of frequent... as determined by the telephone closure procedure is reported. In this time, it is realized BART's completed schedule data for system operation as "unrealistically optimistic."
Fail-safe concepts with reference to the BART ATC system

The following excerpts are from a paper by Dr. William R. Boyce, on fail-safe concepts with reference to the BART ATC system. The paper was presented at the PUC hearings in 1974.

"So why is there so much controversy over the sys-
tem and its safety? One [reason] is the inherent dif-
ticulty of achieving a fail-safe system. We do not say
that the system BART selected is the only one
might have chosen. We do think it is the best of sev-
eral possible systems... The other reason for the con-
troversy is simply a matter of alphabet soup, and the
people who prepared the Report, I'm sure they
know that the best way to get facts is to go to the
best possible source—Westinghouse—if you're
going to write a report on the BART train-control sys-
tem.

"I don't say that Westinghouse is the only source
of information, but certainly the company building
and installing it was one of the logical places to go
for information..."

"The most important single matter is... how to

in mid-December BART fitted off-the-shelf cast iron
mechanical wheel scrubbers to a BART vehicle and
tested them on a track section not yet in revenue
service. The scrubbers have apparently scraped off
the castle points on the rails. It is hoped that they
will be successful enough to permit the signals to be
shunted adequately.

Westinghouse's Woodward Johnson believes that the
scrubbers offer the best solution to the "dead" train
detection problem.

Spiking the switches
BART has verified the report carried in the news
media that 29 of the 49 switches on the Oakland-Frem-
ont line have been spiked shot because BART discov-
ered the switches sometimes tracking open by
unexpectedly opening while trains are passing over.
Because of the spiking, all of the siding along the line
have been blocked off, thereby making it inconvenient
to use a siding when necessary.

Blue ribbon panel reports
On December 19, 1972, special three-man panel ap-
pointed by the California State Senate Public Utilities
and Corporations Committee began its study of the al-
leged deficiencies in the BART system. The panel
members were William Bodies, Occidental Electric
engineer; Bernard M. Oliver, vice president of R&D
for Hewlett-Packard Co., Palo Alto; and Clarence A.
Lovell, a Fair Fax, Va., consultant who has designed a
number of electronic systems.

The panel concluded its study on January 31, and as
this issue of Spectrum goes to press, we are in receipt
of the panel's final report. Among its salient findings:

- The panel was satisfied that BART is reasonably safe
  and represents a suitable interim measure. However,
  the design of the BART Automatic Train Control system
  will not provide adequate passenger safety under full-
  scale operation; and (2) modifications can be made and
  back-up added to the present design that will provide
  adequate passenger safety under all operating conditions.

- The modifications fall into the following classes: (a)
  modifications needed to make the ATC system ade-
  quately safe for full-scale automatic operation; (b)
  additional safety features needed to ensure the system
  adequately safe under full-scale operation in the
  manual and mixed manual-automatic modes of opera-
  tion; and (c) further modifications and additions to
  the system that, combined with the above hardware
  changes, will permit the system to meet the standard of safety to be
  achieved in public transportation.

Recommendations for such modifications related to
each of the three areas are presented in the report. We
shall examine these in detail in the

- Wheel scrubber may solve train-detection problem
BART's train-detection scheme requires the shunt-
ing of a low-voltage signal from one rail, through a
turnof wheels, to another rail so that a following train
will receive a signal approach to the train ahead at
less than safe braking distance. As we have pre-
viously noted, corrosion or dirt on the wheels has insu-
lated the wheels from the rails and, thus, has prevented
the shunting action necessary for train detection. But

IEEE spectrum MAGAZINE 1977

36

37

footnotes-Bigger legs in BART

in the train control system. As we have been able to determine, no other
car has felt that this requirement was necessary to
operate a safe mass transit system.

When the system was selected, BART had
no choice but to adopt the manual block procedure
having an attendant at every other station checking
head to see that the track was clear... In three
months of operation, the not a single re-
report and instance of a train not being detected.

"I'm not sure that it is clearly understood... that
BART trains are operating every day under full auto-
matic control. Occasionally, a train would be manually
stopped at a station and then returned to automatic
control... I hope we all understand that manual block proce-
dures do not replace automatic controls.

The PUC hearings
Last November 27, PUC conducted a two-day field
inspection of the trains during which more than 100 instances of failure of equip-
ment to function properly were noted. The most frequent
defect in the rolling stock was that trains, running
under full automatic control, would miss their
stations and the attendants had to press "stop" buttons to
halt them. Alan, other trains would accelerate unexpected-
ly because the ATC system was not informing the
operator... occasionally, a train would travel at only half speed;
and there was sporadic difficulty with doors that
would not open or close. These incidents, and numerous micro-
computer-related problems, was what VA.

Vakas needed for the report: "As long as there is
one scintilla of evidence that raises a doubt of the
safety of the passengers, it must be reckoned.

On the matter of the computer problem at
Keithley, an engineer-analyst in Alan Post's office, testified on
the Fremont accident of October 2. He alleged that
BART engineers were trying to test data in calculat-
ing the speed of the runaway train at 30 m/h (42
km/h) when it struck the sand barrier. In his test-
imony, Keithley also commented on BART's "faulty
crystal oscillator" problem, and said, Keit-
ley, are subject to many environmental influences,
such as, air pressure, temperature, vibration, shock,
and the way in which they are mounted.

Holger Hohmann, an electrical engineer, considers
BART's ATC system to be unnecessarily complex. He regarded the crystal mal-
function explanation, however, as an "incredible con-
descension" that might have occurred in an "adequate system. He then proceeded
to explain to the senators how the open-loop system was designed to operate on the "absolute assumptions made by BART witnesses would indicate
to have direct, personal knowlege of what they say."

As asked for comment on the BART and Westinghouse
teaching reference to questions on train op-
ations, Westinghouse indicated that "technical problems would
in another development, David Hammond,
BART's assistant general manager, submitted his resigna-
tion late in January, effective March 1.