COMPREHENSIVE
HEALTH SERVICES, INC.

December 1, 1972

After my testimony on November 21st, to the Senate Public Utilities Committee in support of the BART report by A. Alan Post, several members of the press asked me if I would put down in writing my lay-language description of the BART automatic train control system.

The enclosed "BART Train Control Game" will give you a good idea of how the critical train detection and speed control electronics operate.

The experiments suggested will make you an expert on why it does not work.

The author of this story is more Will Harvey than Dr. Willard Harvey Wattenburg, but this description may be the only way the non-technical public will have a chance to understand the issues. And this is all there is to the "highly sophisticated" system. The rest of the electronics, master control center computers, etc., are not in direct communication with trains.

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THE BART TRAIN CONTROL GAME

Written for the Board of Directors
Bay Area Rapid Transit District
by Willard Harvey Wattenburg
November 22, 1972

The purpose of this game is not to play by the rules as of November 1972, but to challenge the reader to invent changes in the rules which provide the player with a better chance of survival against the cruel laws of physics. However, the reader is not allowed to call upon the best of our twentieth century technology, the use of which would require intolerable delays in the game. He may use only common sense.

As we go along, we will occasionally point out to those who might be interested the similarities between our game and an actual train control system which has become a source of concern to a great many people in the San Francisco area, with the possible exception of the Bay Area Rapid Transit District headquarters staff.

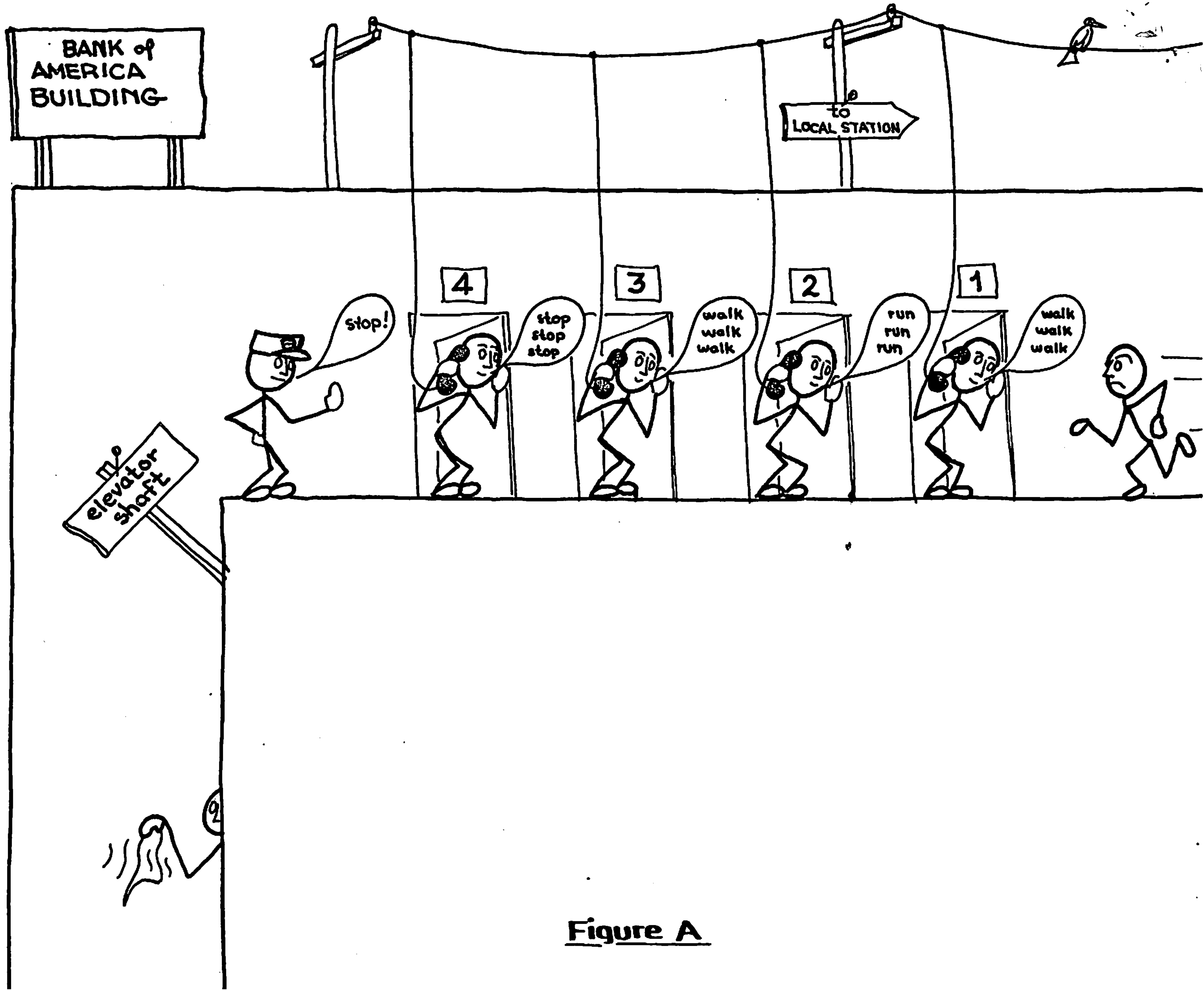
BANK of AMERICA BUILDING
to LOCAL STATION
elevator shaft
stop!
4
stop stop stop
3
walk walk walk
2
run run run
1
walk walk walk

Figure A

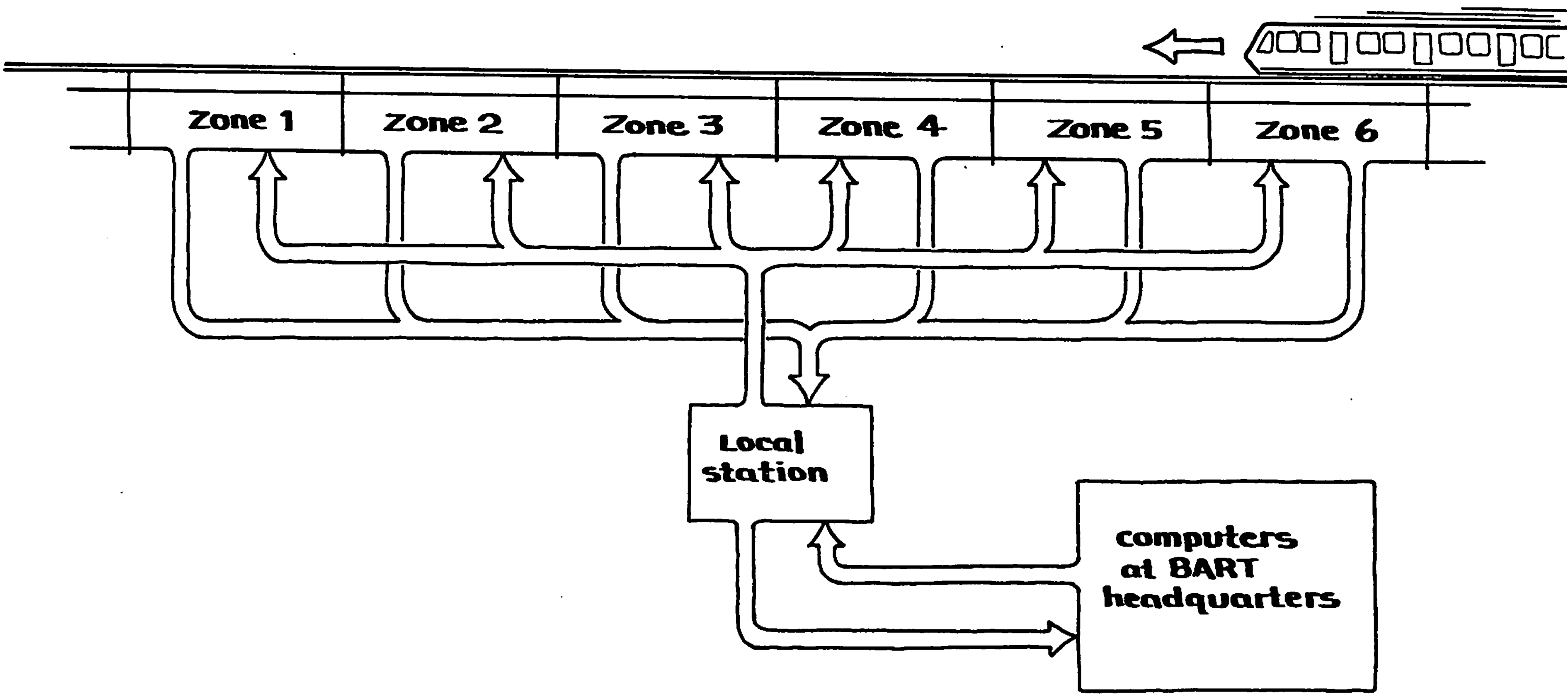
Zone 1
Zone 2
Zone 3
Zone 4
Zone 5
Zone 6
Local station
computers at BART headquarters

Figure B

4

November 1972:

Figure A shows the playing field. It is a long, narrow corridor on the tenth floor of the Bank of American building in San Francisco. There are four doors along the corridor. A clerk is stationed at each door. Each clerk is holding a telephone to his ear. Each telephone is connected to one Local Station operator downstairs in the building.

The corridor is only wide enough to pass through. It is pitch dark at all times. Occasionally, the polished floor is wet due to circumstances beyond management's control. There is an elevator on the right which opens into the corridor at the point marked START. At the opposite end of the corridor is an open elevator shaft, which, due to an arithmetic error in specifications, was never sealed.

The management has decided that each office-bound employee must be subjected to a daily stress situation before he is allowed to go home. Each employee is required to run the corridor once before leaving the building. Realizing the hazardous condition that exists at the open elevator shaft, the management has placed a guard just before the door.

Now the rules and operational details work as follows:

The clerks along the corridor whisper commands to the runner who alights from his elevator at a walking pace. There are three commands: WALK, RUN and STOP. The Local Station operator issues appropriate commands to the clerks over their telephone lines, and the clerks repeat each command to verify they have received the proper command. Each clerk is continuously receiving a command, thirty times a minute, and he continuously repeats each command thirty times a minute. Hence, normally he has no time to leave the phone. Now, this is important, as you will soon see.

When a clerk spots a runner go by, he whispers the latest command he has received from the Local Station operator. The runner must obey the command, if he hears it. If not, he continues at the pace indicated by the last command he heard. (This is also important, as you will see).

In the process of whispering to the runner, the clerk is forced to interrupt his next answer-back to the Local Station operator. Local Station takes note of this error in communication, and assumes that a runner must have passed by the clerk or stopped near the clerk. Thus does the Local Station monitor the progress of the runner down the corridor and back.

The rules of the game require that each runner be accelerated to RUN speed at least once along the way. The sequence of commands given at each position in Figure A will accomplish this purpose. But, good sense also dictates that the runner be slowed down from RUN by a WALK, STOP sequence before nearing the open elevator shaft.

This is called a SPEED PROFILE.

But, just in case some runner misses a command, we've stationed a guard at the open shaft. However, to make the game interesting we require the guard to shout a STOP! command before he is allowed to place himself between a runner and the open shaft.

Well, enough of this silly game. The rules and the means employed to implement them are obviously so unsophisticated that no intelligent person would play. You think so? Let's look at the present BART train control system.

Figure B is a diagram of how trains on the track are controlled by a Local Station which monitors the track in both directions beyond the station. The track is divided into sections called Speed Zones. The Local Station is at all times sending speed commands to each Speed Zone, and electronic equipment at each Speed Zone is continuously repeating the commands it receives back to the Local Station for verification--just like the clerks in our game.

Each Speed Zone is waiting for a train to pass by. When a train appears on its section of track, the Speed Zone <u>whispers</u> its command to the trains in the same way a radio station sends music to your radio antenna at home. The tracks in the Speed Zone form the radio station antenna and the train has its receiving antenna mounted underneath the front of the cab, near the tracks.

Now, a Local Station in BART is supposed to learn of the presence of a train within a given Speed Zone it controls when the Speed Zone makes an error in repeating back some speed command sent to it by the Local Station--just like the clerk, who leaves the phone for an instant to whisper to a runner in our game.

In BART, this interruption of normal conversation is supposed to come about because the iron wheels of a train "short out" the Speed Zone antenna (the tracks) and "mess up" the message (speed command) the track-side electronics is normally sending back to the Local Station for verification.

So this is not so much different than the situation we have in our game. The Local Station operator in our game can only surmise that a runner is near or passing a clerk in the corridor when the clerk fails to respond for an instant because he is whispering to the runner.

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Any reasonably intelligent corporate complovee, familiar with the frailties of seemingly efficient administrative procedures, would baulk at playing our game as is. Who ever heard of generating information by the absence of information? It is necessary in some situations, but not in this case.

So along comes a runner who gets a good look at the open elevator shaft. He takes matters into his own hands and decides to improve the odds for his survival. Each time he passes a clerk he grabs the clerk's telephone and whistles into the mouthpiece. Then he listens to what the surprised clerk has to say. In the meantime, the Local Station operator is complaining about the high-pitched tone that interrupted her conversation with the clerk. But she knows something happened at his position in the corridor. The runner must be there. Note that this is still not proof to the Local Station downstairs that the runner has properly heard and obeyed the message. (But, as I said, we are stuck with the communication hardware now installed in BART, which does not provide for direct communication between trains and local station control). Hence, our runner can take more positive action. And so must your trains.

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Can you think of any reasonable situations that might come up to fool the Local Station? Other than a runner passing by?

In the BART ATC system, a speed command is injected in the tracks within a Speed Zone through the use of two audio frequency signals (which, if you could hear them, would sound much like the musical bleeps heard on the latest telephones right after you dial). The Local Station is constantly sending speed commands and the Speed Zone equipment is constantly sending the same speed commands back to the Local Station. When a train enters the Speed Zone, it is supposed to break this communication link by its pressure on the track (at least that is what the designers hoped for) and thereby indicate its presence within that Speed Zone.

The Local Station is continuously sending a speed command to the Speed Zone waiting for a train to pick it up. This command is similar to a telephone number, a sequence of digits smaller in number but with the same purpose: to ring a particular bell within the speed control electronics on board a train that comes within the Speed Zone section of the tracks.

The telephone number (speed command) is injected electrically into the tracks, in much the same way that dialing pulses are generated on a telephone line by the movement of a telephone dial. The sequence of pulses, or digits, is repeated three times each second until a train appears on the tracks within the Speed Zone and acknowledges that it has received the message. But here is another problem. <u>There is no explicit acknowledgement by a train that a speed command has been received</u>. Reception of a speed command is assumed, not proven.

TRAIN DETECTION

The manner in which a train is supposed to "mess up" a speed command, and thereby indicate its presence in a particular BART speed zone works as follows: Suppose you want to know if the guy in the next room is trying to use your telephone. His phone and yours are on the same line, i.e., he has an extension phone on your line. Hence, you are not allowed to call him or vice-versa. So instead you begin dialing a number somehwere that you know will not answer, and you keep this up forever.

Now, if he picks up his extension and attempts to dial out, he will mess up the dialing digits that you are generating and thereby cause you to reach some number other than the one you have been repeatedly dialing. This is supposed to tell you that he is on your line. Try this experiment at home, and you'll get some appreciation of the problem.

The scheme works, marginally well, if the other guy promises to flash his receiver button several times, with firm resolve, each time he picks up his phone and you are smart enough to always detect when you connect to a number other than the one you were dialing.

But with all the utility of a telephone, why would anyone rely on such a scheme to establish basic contact? Suppose your life depended on knowing when the other fellow was trying to use the telephone?

By the way, there is a command link within some telephone systems which works exactly like the speed command sending cycle in the BART system. This is a feature built in some telephone central offices which allows the repair man to easily identify the number of a line he is working on. He dials a special number and the central office equipment answers back with the digits of the number assigned to the line he is working on. The number is 640 in the Oakland-Berkeley area.

Pretend you are a local station sending out a speed command. Dial 640 and hear the speed command (your own telephone number) repeated back to you by a mechanical voice from the telephone central office.

Now ask a friend to play like a train in one of your speed zones. He picks up an extension phone on your line while you're dialing 640. This should mess up your dialing.

Now note how many times you still hear the same mechanical voice. Ops! That was a train that just went by your station, and you didn't even know it was there.

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Right now the Westinghouse designers are relying upon the electrical conductivity of the train wheels on the track to short-circuit or mess up a speed command that is travelling in the tracks on its way back to the Local Station. But the low power signals and signal frequencies they choose to use are not reliably short-circuited by the train wheel, as is the case with standard train detection circuits which use higher power and lower signal frequencies. (Note that I suggest your problem is not just the low power being used--but most any junior electrical engineer can explain this observation to your engineers if they are incredulous).

Now, your trains must be more aggressive--just as our runner is now doing by whistling into the clerk's phone as he passes. You can mount equipment on board each train that repeatedly "flashes the button" to better "mess up" the dial pulses sent out by a local station. Your ATC system uses two frequencies between 9000 and 12,000 cycles per second to transmit speed commands in each Speed Zone section of track. The two frequencies are switched on and off to indicate the pulses which make up a valid speed command.

Hence, you should mount an active transmitter underneath each train, which transmitter periodically sends out a burst of energy in the 9000 to 12,000 cycles per second range and messes up the signals in the track. There are better ways, but this scheme allows you to use existing equipment similar to that already installed on trains and at wayside, hopefully saving development time.

The train transmitter should turn on for a fraction of a second each second, say 1/5 of a second on then followed by 4/5 of a second off. This will mess up about three of the pulses in a 6-pulse speed command which is being repeated three times each second in the tracks. The train has ample opportunity to read the next copy of the speed command during the 4/5 second time that its mess-up transmitter is off. Try it-- you'll like it.

Of course, your engineers will complain that this scheme destroys some of the beauty in their simple system of communication, or that it will cost too much to mount appropriate transmitters on each train, or that this scheme will require some modification of the local station electronics.

I will be happy to answer all such complaints with a simple demonstration if you will make available a train and a section of track for a few hours in the night.

Of course, all this assumes that Westinghouse has not made drastic changes to the equipment and elecrronic circuit descriptions which were valid as of October 1972.

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SPEED FAIL-SAFE

Well, so much for this. We've fixed up the communication link so that most of the runners have confidence that they are properly notifying the Local Station operator of their position as they traverse this perilous course.

But the word gets out to the rest of the employees who must play the game each day that the system was not perfect to begin with, as advertised. This annoys some of them. Their curiousity is sparked, and they begin to question the rest of the rules.

Suddenly it occurs to one previous runner that he once found himself approaching the open shaft at the end of the corridor at RUN speed. He was lucky. The guard stopped him in time. He cursed himself later because he had forgotten to turn up his hearing-aid before he played the game that day. He heard the RUN command whispered by clerk number two, but he missed the rest of the commands given to him down the corridor. Now that was silly. Why did he keep going at RUN speed when he knew he had passed the next clerk?

Alas! There's the answer. He knows approximately the distance between clerks spaced down the corridor. From now on, he resolves, he'll never go farther than the next clerk at RUN speed. If he doesn't hear the next whispered speed command, he'll slow down to WALK whether the management likes it or not.

In fact, if he misses two commands in a row, he'll STOP.

The word soon gets out to the other employees. Somebody has come up with a way to beat the system--without asking management. Everybody stops sweating for awhile. The game is even fun now.

Now this observation is worth some thought. It just so happens that a rather inexpensive modification to the speed control electronics on board the BART trains could make smart runners out of them all.

A simple timing circuit can be added which will allow each of the speed commands to stay in effect only for a maximum lenght of time, unless another valid speed command is received within the specified time. If a train misses the next command, it will automatically decrease its speed, or stop. The virtue of this rule is that the train will end up doing just what the Westinghouse system would like it to do, decelerate smoothly to a stop--even if the Westinghouse system is sent back for repairs.

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Try it--you'll like it. I'll give you the parts for the prototype if it seems difficult.

What I have called upon to partially fail-safe our game is a time honored principle known as "positive control" or "fail-safe by exception," wherein systems are designed such that dangerous movements are only allowed to continue so long as there is periodic reinforcement to do so. It is claimed that this principle was first discovered by an engineer who noted that most mules stop when you drop the reins.

The ten-cent return spring on the accelerator of your car is the perfect embodiment of this principle.

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