ASTREE: A Global Command, Control, and Communication System

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ASTREE is a research project on a global command, control, and communication system for train control and traffic management developed by the French National Railways (SNCF). It is based on maintaining a distributed data base of up-to-date, accurate, and comprehensive representation of route layout and train progress. Computer applications use the image of the actual situation gathered in the data base to make (or, in some cases, to help human operators make) all decisions regarding route setting and train control. The results are transmitted back to wayside equipment and to locomotives, where they are displayed and enforced, if need be, by a penalty brake application. Development began in early 1986 and has enjoyed important resources. After a few years of definition of requirements, technological component testing, and architecture design, the first integrated test is under way with extensions planned. A large-scale, yet not vital, test is slated for 1992. If the results from the tests meet the technical and economic expectations, a full-fledged implementation could be operational on one route by 1997.

In 1986 the French National Railways (SNCF) embarked on a large-scale research program to develop a global command, control, and communication system for train operation and railroad management called ASTREE. This paper highlights those points where the emphasis or the approach is felt to be different from those of Advanced Train Control Systems (ATCS) level 40 and reports ASTREE's current status and anticipated development.

ASTREE'S MAIN FEATURES

Integrated Approach

ASTREE is based on few simple ideas:

- Equip every train with location and communication capabilities.
- Connect a distributed computer system to switches—so as to monitor routes—and to trains to keep track of their positions.
- Keep in a distributed data base an up-to-date, accurate, and comprehensive image of the road and of the trains.
- Develop software tools that build on this representation to make (or help make) all decisions related to train control and network management.
- Transmit their output back to wayside equipment and to trains in the form of controls (such as lining switches), restrictions, authorities, or advice.

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Sophisticated Train Location System

ASTREE's positioning philosophy relies on the following principles:

- The route set ahead of a train is monitored by ground-based equipment and the train progress on this route is determined by the train itself.
- The train location is defined by an interval for vital applications and by an average for nonvital applications.
- The location interval is determined by an odometric unit, which blends and processes information from a number of sources.

Ground-Based Route Monitoring and Train-Based Progress Measurement

Avoiding rear-end, head-on, or sideways collisions requires knowing not only on which track a train is running, which could be left to the train itself to determine, but also what route is set ahead of it. This is necessary to make sure that the authority to proceed granted to one train does not conflict with that granted to another train and not yet released by the latter train, or that access is not prohibited for some other reason such as maintenance of way.

Monitoring the route from the ground is also a natural consequence of the fact that in most cases routes are set by ASTREE.

The decision to let the train determine its own position on the known route is based on several considerations:

- A train must constantly know its own position and speed so that it may brake if, and only if, this is necessary to avoid exceeding its limit of authority.
- A train must be able to report its most recent position when the ground-based control center needs this information, so as to efficiently release and allocate track segments on a geographically continuous basis.
- This continuous on-board knowledge is best acquired from on-board sensors.

Definition of a Vital Location Interval

For vital applications, ASTREE defines two positions:

- A foremost position, such that the probability that the head end of the train be actually beyond this position is lower than a predetermined very demanding figure; and

- A rearmost position, such that the probability that the rear end has not cleared this position is lower than this predetermined figure.

The foremost position is used by the train itself for cab-signaling purposes or brake application. It is used by the ground control center to set switches early enough and issue warnings such as to a road crossing protection. The rearmost position is used by the control center to take track ownership back from one train and possibly grant it to another train, to unlock points, or to reopen grade crossing barriers.

The span between foremost and rearmost positions has two components:

- The train length, which therefore must be known in a vital manner (or, if not, an upper limit of which must be known) and which in most cases is derived from train consist (plus whatever slack there may be); and
- The uncertainty interval about the position of the head end.

Determining the head end vital interval is the task of the odometric unit.

Derivation of Vital Location Interval by Odometric Unit

The odometric unit is probably one of ASTREE's unique features when compared with ATCS. Because it represents a major development effort and will be a significant item of the on-board equipment cost, an explanation is offered on why SNCF puts such emphasis on keeping the interval small where a train location is known to be.

The volume of traffic on the French railroad is low by American standards; however, the traffic density expressed in number of trains/unit of track mileage is very high and generates severe capacity problems on at least some routes. This reflects not only the fact that the length of a French freight train is significantly shorter than that of its American counterpart, but also that passenger train traffic is very high. Keeping headways to a minimum is therefore a major concern, which translates into a desire to limit the uncertainty about a train's location.

It has been decided to base the train location not only on absolute fixes such as those derived from (satellite) radio determination, but on a measurement of the distance traveled. This integration approach entails a creeping error, which must be bounded by an adjustment process at some known places on the track.

The distance traveled is derived from a number of sensors, actually wheel rotation counters and Doppler radars, but other more exotic sensors are also being developed. Measurement based on wheel rotation is plagued by wheel slippage, especially where the tractive or braking effort is high. Doppler radars are not affected by these problems but may be subject to adverse atmospheric conditions that can, however, be overcome in most cases through efficient signal processing. Sensors measuring the pressure in the brake pipe or the tractive effort give indications about the confidence to be placed in one sensor or another. Through Kallmann filtering and the use of a model representation of the train behavior, an uncertainty interval can be derived, the limits of which can be relied upon as vital data. The computer that crunches the numbers must, of course, be vital. It can be seen that the odometric unit is a very significant component of ASTREE.

The location adjustment process is based on detecting microwave tags placed on ties through an on-board interrogator. It is another responsibility of the odometric unit to look for tags where they are expected to be detected and to adjust the uncertainty interval based on their detection. Failure to detect such a tag does not result in a degraded safety level but rather in an accuracy that further degrades until another tag may be correctly read.

The overall absolute accuracy is a function of the relative accuracy of distance measurement and of the spacing of tags. Current values are better than 1 percent for the relative accuracy, and 1 km for tag spacing, but the best return on investment may come from different values. It should be noted that a tag brings an improved accuracy downstream, which may lead to the installation of such tags at the limits of station areas.

Sophisticated Use of SNCF's Current Radio

The fixed-to-mobile transmissions rely on an advanced version of SNCF's current ground-to-train radio. This radio operates in the 450 MHz band. It is compatible with the International Union of Railways (UIC) standard.

Where U.S. radios operate in the VHF band for voice, and in the 900 MHz band for data, SNCF's UHF radio will transmit both voice and data. This decision is based on several reasons, an important one being that no frequency band in the 900 MHz range has yet been allocated to European railways. Other reasons for using this radio were that it already exists, which makes adapting it less costly than investing in additional facilities, and its good coverage quality (base stations are so closely spaced—4 mi odd—that when one is down, a train can still be reached through an adjacent station).

However, the most surprising reason for using this radio to carry ASTREE's data traffic is that is offers sufficient capacity. Estimates based on modeling ASTREE's behavior indicate that, for the most heavily loaded base station at the busiest hour, the highest priority traffic is on the order of 20 messages per minute, both in the train-to-ground direction, which consists largely of location reports, and in the ground-to-train direction which are mostly made up of authorities to proceed (consisting of a limit of authority along with a maximum speed indication and the braking parameters to be used by the train). The reason for this limited volume rests with ASTREE's synergy: the location reported by a train will be used by many applications and, conversely, an authority to proceed, although a simple message, results from a complex processing of a large amount of data.

The main technical differences between ASTREE's radio and that of ATCS will be discussed as follows.

Resource Sharing Between Voice and Data

UIC 450 MHz radio is basically analog, with a 12.5 kHz channel spacing. ASTREE data are staggered quarterly phase shift keying (SQPSK) modulated at a rate of 2400 bits per second (bps). When no voice traffic is present, the full channel capacity may be used for data, at least in the ground-to-train direction. When voice traffic is present, it take precedence over data traffic but uses only three-fourths of the available capacity.

This is achieved through time compression-expansion. One second of speech, actually 1.040 sec, is digitized, stored and replayed in analog mode in 780 ms. At the receiving site, it is digitized and replayed in 1.040 sec. Voice quality is adequate. The remaining 260 ms every second still provide enough capacity to transmit two 255-bit frames in each direction.

When there is no voice traffic, the capacity available for data is eight 255-bit frames per second. Today, the actual use of voice radio is low (a few percent), which does not imply that it is unimportant. An intuitive feeling is that the use of voice radio will be even lower when most of the reasons for its use are taken care of by ASTREE.

It will be argued that using two radios rather than one offers a backup possibility. ASTREE will also be looking for some sort of redundancy, but preferably through the use of another medium rather than through a mere duplication of equipment. One such possibility would be using Locstar, the European cousin of Geostar, but it has not been possible yet to assess its ability to support ground-to-train traffic. Another possibility under consideration consists of using microwave tags that provide for two-way communication to add a limited data transmission capability to their location adjustment function.

Data Protection

A significant difference between ASTREE's radio and the one developed for ATCS is that, as far as we understand, the latter is considered as a vital component and therefore designed so as to allow an extremely low percentage of undetected errors.

ASTREE's approach, by contrast, is to put no strong demand on the degree of safety requested from the communications components. This by no means implies that ASTREE is not interested in a very low error rate, but rather that achieving an extremely low undetected error rate seems so important that the communications segment could not be trusted for fear that errors might occur in the terminal ends of the communication link.

Therefore, where vital transmission is required, it is the task of the application process that creates the data to supplement them with an extensive redundancy check sequence, and it is the responsibility of the application process that is about to make use of the received data to check their integrity against the received redundancy check sequence. Under these circumstances, it was not considered appropriate to spend any additional resources to improve the error rate on the communications segment itself.

In addition, failure of delivery of a message is not unsafe: a message will usually convey permission, not a restriction. In this manner, if for some reason the link is no longer available and no further message can get through, trains will come to a safe stop rather than blindly run farther. An exception is that if a dangerous event occurs at the last minute (e.g., an automobile falls from a bridge after an authority to proceed had checked that the track was clear from obstacles), an attempt will be made to transmit an alert to make the train stop.

It has been seen that safe transmission is obtained through an end-to-end error detection and retransmission mechanism. In addition to this, a forward error correcting (FEC) code is appended to the transmitted frames. This has nothing to do with safety because it is already provided by the error-detection scheme. FEC addresses two concerns, namely limiting the number of unwanted train brakings and reducing the cost for covering additional lines.

As will be indicated, the line access discipline is geared to waiting as long as possible before granting a train an extension of its authority to proceed. This attitude allows this extension to be made based on the latest possible known position of a train ahead, and therefore to grant the longest possible section of track, thereby minimizing the number of messages on the mileage covered. This attitude would be jeopardized if for some reason the new authority to proceed could not get through in time to avoid a train braking. One possible reason could be message collisions; the selected line discipline was chosen to minimize this possibility. Another possible reason rests with transmission errors. It is to decrease the occurrences of such errors that FEC is used.

Another potential advantage of FEC is to minimize the investment required to cover low-traffic tracks (with no voice capability on these lines). ASTREE does not demand a continuous coverage but only that the limit of an authority to proceed does not happen to be in a coverage gap, because a locomotive halted in such a gap would never receive the authority to proceed farther. It is felt that an appropriate attitude would be to install the base stations where they are easy to install and where most of the action takes place (i.e., in the stations, which are more closely spaced in France than in most of the U.S. or Canada). Although coverage gaps between adjacent stations would exist and would be accepted, it is felt that FEC may help reduce the number or size of such gaps.

A Line Discipline Based on "Intelligent" Polling

Line discipline is also an area in which ASTREE's options seem to differ from those of ATCS. ATCS radio has selected a contention scheme (free access) improved by the "busy-bit" technique, whereby a base station indicates to potential transmitters that it is already busy receiving a message. By contrast, ASTREE's radio makes use of an "intelligent" polling scheme.

This choice is based on three objectives: to maximize channel efficiency, to control transmission delays, and to cope with possible coverage gaps. It is also based on two features of ASTREE: the control center knows where the mobiles are located and is aware of their need to transmit. It is further influenced by a specific feature of UIC radio, whereby all the mobiles on a route transmit on one frequency, which may result in the transmission from one mobile at the fringe of a cell area being corrupted by the simultaneous transmission from a mobile at the fringe of an adjacent cell.

ASTREE's control center knows how far a train has been authorized to proceed, its current speed, and when it will have to begin braking if not granted a further authority. It knows what train has to report its position so that it may release ownership of the track segment cleared by its rear end and so that part or all of this track may be allocated to the other train. The control center therefore knows when it needs the position of a train and can therefore keep the initiative to query this location.

This "intelligent" attitude was preferred to a systematic cyclic polling, which would translate into unnecessary messages or into using outdated locations, which would in turn result in smaller track allocations and in more frequent messages. It was also preferred to a basic contention method where it was feared that trains would unnecessarily report their position, or that message collisions would either entail a time-out and retransmit procedure or lead to using outdated train locations. Although a busy-bit technique does prevent most collisions, it was felt it could not avoid some undesirable transmission delays nor completely eliminate corruption from messages transmitted in adjacent cells.

The rigid discipline enforced by the ground control center does, however, leave room for free emergency reporting. To this end, some time slots are not assigned to a specific transmitter but rather left open for emergency messages.

The above line discipline is enforced by a communications controller. This controller is responsible for routing a message to the appropriate base station (using location from ASTREE). To better balance the radio traffic, the controller can force a train covered by several base stations to switch to the appropriate frequency. It manages ground-to-train transmission time slots, because it knows how urgent each message is and how to share a frame between packets or divide a long packet into multiple frames. It also manages train-to-ground time slots, avoiding collisions between messages transmitted by trains located in the same cell or in adjacent ones. It can also cope with coverage gaps.

Flexible Route Control

Route control is provided by ASTREE either directly—ASTREE then controls and monitors switches and takes care of interlocking—or indirectly, by connecting to existing interlocking plant. Each solution may be used where most appropriate. Over time, it is possible to migrate from one solution to the other.

Using Existing Interlockings

Using existing interlockings implies that routes will be controlled and monitored. This is an attractive solution in which technology is modern and allows for remote control. In cases in which technology is less modern, it may be necessary to control routes indirectly by displaying messages to a switchman; route monitoring is, however, direct.

To safely release routes, an existing interlocking must know the locations of the trains. This knowledge may be provided by ASTREE. It is, however, simpler to keep the existing island track circuits. Yet there is no need to keep wayside signaling, which is redundant with ASTREE's cab-signaling, or may even be more restrictive in some cases.

ASTREE-Provided Interlocking

If not provided by an existing interlocking plant, the interlocking process must be provided by ASTREE. The life-critical aspect of it—which demands that no section of track, switch, or apparatus be granted to more than one train at a time, and that no point be unlocked and operated if still allocated to a train—is part of the more general "free-track assurance" of ASTREE. This mechanism consists of allowing a train to proceed as far as a given point only if it is possible to grant it the (temporary) exclusive ownership of all the necessary resources. Compliance is enforced through brake application if a train's speed is such that the train is about to exceed its limit of authority or its allowed speed.

Other aspects of interlocking are dealt with in a nonvital way. One of them is route protection. Because the free-track assurance mechanism will, if necessary, safely halt a train before it crosses another train's route, only the best efforts will be made not to let it come close to this situation. Similarly, only in a nonvital manner will some routes be set in such a way as to minimize the consequences of a possible free-running of a train or a car, because a collision could only result from the simultaneous occurrence of a drift and of a faulty implementation of route protection.

ASTREE's route interlocking therefore allows any feasible route to be set, rather than only those routes built into the interlocking plant. This means that it may pay off to let ASTREE handle interlockings, even when an existing interlocking plant is of modern technology, when it is desired to modify the track diagram significantly. It may also prove worthwhile when bidirectional operation is desired.

If ASTREE provides for the interlocking function, it then must control and monitor switches directly. This control and monitoring may be centralized where the former interlocking plant used to be and then use the conventional point control and monitoring tools. It may also be distributed in the field. ASTREE allows for both types. In particular, a distributed system in which a central vital computer is connected through a multidrop link to wayside nonvital equipment is under development. In this system, the central vital computer transmits a random bit stream to wayside equipment that attempts to have this bit stream go through a contact to be monitored. If successful, the bit stream is transcoded in a device in the immediate vicinity of the contact in a way that is specific to this contact and then returned to the central computer. This computer checks the received bit stream against the anticipated result and decides that the contact was actually closed only if the redundant bit stream matches what it is supposed to be. A safe control is based on using the previously mentioned monitoring technique and relying on the fact that a transformer will let only alternative current through.

Simple Consist Acquisition and Train Integrity Checking

Knowing a train consist and the technical characteristics of the vehicles of which it is composed is essential for efficient traffic management and for safe train control. A continuous train integrity assurance is a necessity to ensure safety. Because continuous train consist checking is difficult with freight trains that do not have a train line, train consist acquisition and integrity checking are dealt with separately.

Train Consist Acquisition

Knowing a train consist is not only of commercial interest for work-order reporting. It is necessary to know how long a train is to safely control meets or passes, train separation, and point release. Knowing a train consist is one possible way to acquire this knowledge. Knowing the maximum permissible speed of each vehicle is necessary to determine that of the train. Knowing individual braking characteristics enable the aggregate braking characteristics of the train to be derived. Knowing the individual weight of each vehicle enables train tonnage to be taken into account when making dispatching or pacing decisions.

Automated acquisition of these data implies that each vehicle must be equipped with a device with some transmission capability. As far as passenger trains are concerned, it is possible to acquire this information through a dialogue between cars over the train line. Such a dialogue appears difficult to achieve with freight cars, except with some specialized fixed-consist trains. The difficulty stems from the absence of a train line that could serve both for communication and power supply. It was therefore decided to acquire the relevant information from wayside detectors.

Another difficulty comes from the volume of international traffic in Europe, which means that only internationally agreed solutions are acceptable. In this respect, it should be noted that automatic vehicle identification (AVI) has received new interest, which should lead to the installation of microwave tags on all cars involved in international traffic. These tags are readable when passing in front of ground readers. Their technology is similar to that used for location adjustment.

SNCF has tested a new generation of tags. These tags may be read at speeds in excess of 250 mph. They have a capacity of 2,048 bits, organized in 16 areas of 128 bits (but the new generation has twice this capacity). Some of these areas are read-only. They are used to carry the vehicle identity and its permanent technical data.These data are protected by a high redundancy. Other areas may be modified by a modulated microwave beam when passing in front of a reader. They carry information such as destination yard, payload, or commodity (the newer, higher-capacity tags might even carry some way-bill information). A third type of area can be modified through an on-board series data link to report en route on internal status (temperature for reefers) or events (e.g., door tampering or time of a possible shock).

Readers are placed before and after those places in which train consist may be modified and establish this consist up and down the line. They are connected to an ASTREE control center. Some of them drive several antennas. This allows for a cost-effective way of detecting vehicles on multiple tracks at a given location and enables ASTREE to know which cars enter and leave specific tracks of a complex plant (one of the functions of work-order reporting). Train consist may also change in such places as a smaller industry track where it may not be justified to install and connect a reader. It is considered acceptable to enter the consist modifications manually and to take conservative values for some technical parameters until the exact consist may be checked when passing by the next interrogator.

Without waiting for ASTREE's deployment, SNCF has put this AVI subsystem into operational use on a limited scale. The yards of Lille, Avignon, and Marseille have been equipped with a total of 35 readers, as well as a specialized fleet of 400 freight cars that run between these yards at 100 mph.

Integrity Checking

For safety reasons, train integrity should be permanently monitored. This checking usually comes as an additional benefit when track circuits or axle counters are used for train location purposes. Because ASTREE does away with such trackside equipment, and because the spacing of AVI readers is too large, integrity monitoring must be performed on board.

One possible solution has been adopted by ATCS. End-of-train equipment is attached to the coupler of the last car. Over a radio link, it reports to the locomotive the pressure measured in the brake pipe. This solution has been tested by SNCF and it works successfully. It has not been retained, however, both because it was believed to place demands on the personnel (carrying a rather heavy piece of equipment) and because another solution (which may be more appropriate for Europe's relatively short trains than for America's very long trains) seemed to provide an even better answer.

This solution consists of continuously monitoring the pressure in the brake pipe, the air flow from the compressor, and the setting of the engineer's brake valve. The comparison of these data allows the detection of a train breakup. It also helps to check that the required brake tests were actually performed (but no indication is given as to the outcome). During these tests, it enables the volume of the brake pipe plus the auxiliary air reservoirs from the pressure variation that results from a known variation of the total air mass (itself, the product of the volume of air injected by the compressor times the pressure) to be derived. A change in this volume therefore indicates a consist modification, or the isolation of some brakes or of part of the brake pipe.

As for the AVI subsystem, it is possible that ASTREE's integrity monitoring subsystem could be put into operation before ASTREE's deployment.

ASTREE'S DEVELOPMENT STATUS

ASTREE's main features described above show that its ambitions are similar to those of a full-fledged level 40 ATCS. It has from the start been thought of as a global answer to the command and control problems of the entire French railroad.

Understandably, no management will want to commit itself to huge expenditure without some well-based assurance of the workability and performance of the system, as well as of its return on investment. The initial ideas gave enough confidence on both counts for the management to give a green light to the first steps in the development, but of course each new important phase will have to be supported by convincing evidence.

Reported in this section will therefore be the earlier developments and the present status, followed by the anticipated next steps of development.

History and Current Status

ASTREE's research and development program was launched at the end of 1985. Interestingly enough, the emphasis was then laid on the improved level of safety that would accrue for the whole railroad system, whereas today much attention is also focused on avoiding or postponing investment in additional track capacity, better performance (adherence to schedule, energy saving, flexibility), and of course staff productivity.

From the start the effort was important and centralized. The assemble team included by the end of 1986 some 20 people working full time plus the part-time involvement of many others in the organization. The current level is 30 full-time SNCF employees, or a total of 50 if the staff from suppliers or software houses permanently assigned to the project are taken into account.

Although SNCF is fully aware that developing the future industrial products should be left to suppliers, its role in the development has been and still are not only those of a future operator and client but also those of a design consultant and integrator. The reason for this is that SNCF considers ASTREE as a potential major instrument in its future day-to-day operations and wants to make sure that all the major design choices are made in its own best interest (e.g., train integrity checking could be achieved by using end-of-train equipment or by in-train brake pipe pressure monitoring; this equipment is supplied by different vendors). This attitude is consistent with the approach adopted in the past for all major developments such as Train à Grande Vitesse (TGV). In the first stages of development, therefore, SNCF did the engineering, contracted to industry technological developments for individual components and progressively for subsystems, and acted as the integrator.

A first round with representatives from the various parts of the organization led to a tentative list of potential applications but not to a detailed functional specification. An initial system architecture was designed. Various component tests were performed extensively (e.g., Doppler radars or more exotic distance-traveled sensors, microwave transponders, point-monitoring devices, a new version of radio transmitters). After that, subsystems were contracted (the odometric unit first in a nonfail-safe version then in a fail-safe one, the integrity checking system). In most cases, SNCF kept to itself software development, even for modules as important as the communications handler or the control center main applications, in order to have the know-how and to be in a position to maintain and upgrade the system.

At first, tests involved cars in revenue service or test vehicles. For instance, a TGV set assigned to Switzerland traffic was used as a test bed for odometric sensors. Occasional special runs were also performed, however, for example to test performances at speeds in excess of 250 mph.

In 1990, the system level tests began on a very limited scale.The 5-mi line connecting Bondy, on the major trunk line from Paris to eastern France, to Aulnay, on the major artery from Paris to northern France, was selected, because the number of mobiles to be equipped was small—the passenger rolling stock is constant and few freight trains run during the day. Yet this line offers an interesting test bed: the route is partly double track, partly single track; one interlocking plant is a remote-controlled satellite of an important modern control center and another is an older lever-type one. There are grade crossings, industry tracks, and so on. A control center has been built in the station of Gargan (halfway between Bondy and Aulnay). Although it controls only a few trains and a few miles of track, it has been sized as though it were to control a very large area.

The purpose of this pretest, as it is called, is to demonstrate a preliminary, integrated version of all the functionalities of a full-fledged system. This gives users an opportunity to assess the services, the level of performance, and ergonomics. It also gives the users opportunities to see what changes are needed to this first version.

A major limitation of this test is that it is not implemented in a fail-safe way. No attempt has been made to make it fail-safe because the time needed to develop the system and subsequently certify it would have added undue delay before the first lessons could be drawn from this experiment. Accordingly, trackside signaling has been retained and takes precedence over cab signaling. In addition, most engineers' cabs are not even equipped with cab signaling (although the train sets are fully equipped with location, transmission, and integrity-checking subsystems).

In spite of this limitation, an extensive use is made of ghost (fictitious) trains to test the system's responses to all sorts of situations, including some potentially dangerous ones. These simulated trains appear to the system through real messages, which are actually transmitted over the radio to the appropriate base station (directive antennas are used to transmit to one base station or another). To add some complexity, not only ghost trains have been added, but also ghost switches and ghost tracks (but only ghost trains are allowed to run on ghost tracks).

The system now operates properly. The implemented trainborne functions include system setup (initializing a train when entering the ASTREE-controlled area), measurement of distance traveled, location adjustment, communications, cab signaling, integrity checking, and brake application. The implemented control center functions include train initialization, communications, display (train describer and time sheets), route monitoring, route control, consist acquisition, and authority to proceed. Dispatching makes use of a (modest) real-time expert system.

Next Steps

Some of the next steps have already received formal approval from SNCF's management as well as the requested appropriations. These next steps include extensions to the pretest and a regional test.

The major extension to the pretest will be a fail-safe version, which will have to be certified by the government. Only this will make it possible to operate real trains under ASTREE, and SNCF believes it is a necessary milestone to establish ASTREE's credibility among the potential users.

Other extensions to the pretest are not as well defined: it is anticipated that, on the basis of the lessons drawn from the initial tests, some modules will have to be modified, and some functions will have to be added. Which ones have not been determined yet, but provision has been made for a revised version with extensions.

One possibility under consideration would be to develop the fallback degraded mode of ASTREE into a low-end version, which could be implemented as an operational system on one selected branch line.

The regional test will offer the same functions as the first pretest, but will cover most of the trains running in the Paris-Est region, one of SNCF's 23 regions. About 400 track-mi will be covered, and 80 locomotives or train sets will be equipped. At the peak hour, 86 percent of the train-miles in the Paris-Est region will be covered (the remaining 14 percent will either be unequipped locomotives running through the region or unequipped branch lines).

The objective of the regional test is twofold: first, to demonstrate ASTREE's ability to cope with the processing workload and the communications volume; second, to demonstrate the ability to offer a continuous and dependable service. In particular, the regional test will demonstrate the possibility of reconfiguring the system when a control center fails, or when major parts of the communication network fail. In addition to these objectives, it is believed that much will also be learned from the variety of situations that will have to be faced during this full-size test. As indicated, this step has already been approved by the management of SNCF.

The next step will have to wait for the successful completion of the regional test and for a refined version of the economic evaluation before management approval is sought. This next step could be the implementation of ASTREE on a new high-speed line to be commissioned by the year 1997–1998. This could be the TGV-Est (Paris to Strasburg, and beyond to Mannheim–Stuttgart in Germany), the construction of which has been decided upon by the French government. Again, this next step in the development of ASTREE is purely speculative at this stage and will be subject to the successful completion of the regional test and to the further justification of its return on investment.

International Cooperation

The mere idea of a high-speed train running on a route connecting France and Germany shows that a new train control system can no longer be developed on a purely national basis. A TGV train set cannot be split up to get another locomotive when crossing a border. Were it possible, it would be unthinkable to waste so much time when so much effort is made to run at high speed. This proves that some form of international cooperation is a requirement.

The ultimate goal is the development of a unified European system. Short of this ambitious objective, a more modest one is to achieve enough compatibility for the rolling stock of one railroad to be able to run on the tracks of another—one of the goals of ATCS in America.

This compatibility demands that all interfaces between train and ground be standardized. Actually, there are only three such interfaces in ASTREE: the one between on-board microwave reader and transponders in the track to adjust the dead-reckoning process, the one between on-board radio (and on-board computer) and base stations (and various ground computers) for communication purposes, and the one between trackside microwave interrogator and on-board transponders for AVI.

Everything else may be specific to a railroad. The way one railroad controls and monitors a route, for instance, is of no concern to a foreign train, as long as the host railroad knows how to prevent that train from proceeding until the route has been set. Of course, it is desirable to go further in system harmonization, if only to benefit from a broader market, but each railroad may have its idiosyncrasies that result in its preferred solutions not being those of its neighbors.

Actually, a closer examination shows that a broader compatibility is desirable. A French engineer, for instance, will not drive the same way as a German colleague. The regulations are different today, and the information displayed is also different. For instance, one uses a target speed and the other uses a current maximum speed. Therefore, cooperation toward some harmonization goes beyond a mere technical compatibility.

The French and German railroads have acknowledged the necessity of a joint approach when defining their next-generation train control system. This is why a cooperative program called Artemis was set up between SNCF and Deutsche Bundesbahn (DB) at the end of 1989. In this program, SNCF builds on its ASTREE development. The unofficially stated objective is to install high-speed line equipment on the Paris-Mannheim-Stuttgart that hopefully would be also compatible with SNCF's current high-speed control system, TVM 430, and with DB's current system, LZB.

A broader European effort is sponsored by the European Community within the framework of its Euret (European Research on Transport) program. The objectives are the same, but the rail partners are the 12 railroads of Europe's 12 member states, plus the railroads of Austria and Switzerland. The first research contracts are expected to be awarded by the end of 1991.

What about ATCS? On the one hand, the cost of boring a tunnel between Europe and America does not make it strictly necessary to have a unified approach for some time yet. On the other hand, the concerns on one side of the Atlantic and the other are basically the same, although European railroads—with their more numerous shorter trains, their heavy passenger traffic, and their very high-speed trains—may place somewhat different emphasis on various aspects of train control. Certainly it is in the world railroads' interest to have as broad as possible a market to procure their equipment at the lowest possible cost.