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kuhn @inrets.fr

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TECHNOLOGICAL EVOLUTIONS OF UNMANNED TRANSPORTATION SYSTEMS IN FRANCE

Yves David *

Abstract :

Unmanned operation is becoming a standard for French urban transports on dedicated tracks. With 3 lines in operation, 5 lines in construction and 2 or 3 lines at a design stage, a great experience has been already acquired with this operating mode .

In this paper, it is intended first of all to present briefly the different families of automated systems already in operation or in development in France ; in a second part some significant evolutions in the design of these systems will be detailed and discussed ; in a third part some reflexions on the perspectives of evolution of fully automated systems in the long term will be presented.

1 - The families of urban transport systems in France :

The fully automated transport systems which are in operation or in construction in France may be classed into 3 categories :

- light rail transit lines, which are represented by the VAL family,

* Director of the Center for Research and Evaluation of Automated Transport Systems (CRESTA) of the National Research Institute on Transports and their Safety (INRETS) - 20, Rue Elisée Reclus - F-59650 VILLENEUVE D'ASCQ - FRANCE.

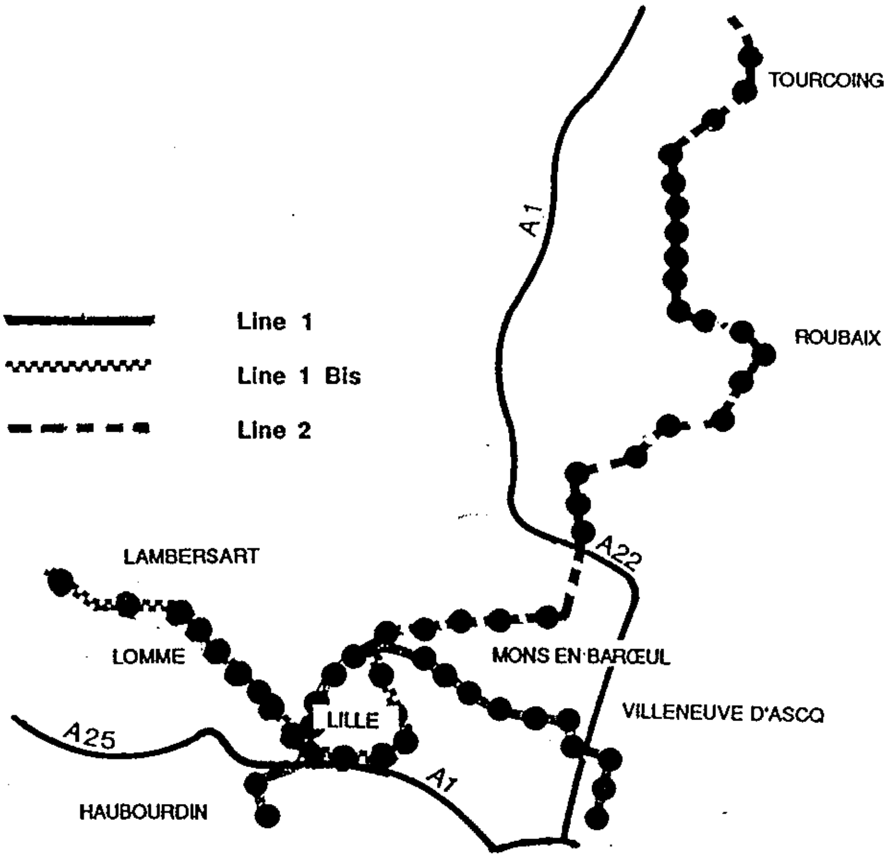

Fig 1 : Lille Metro Line 1 and 1 bis (in operation) and Line 2 (in construction)

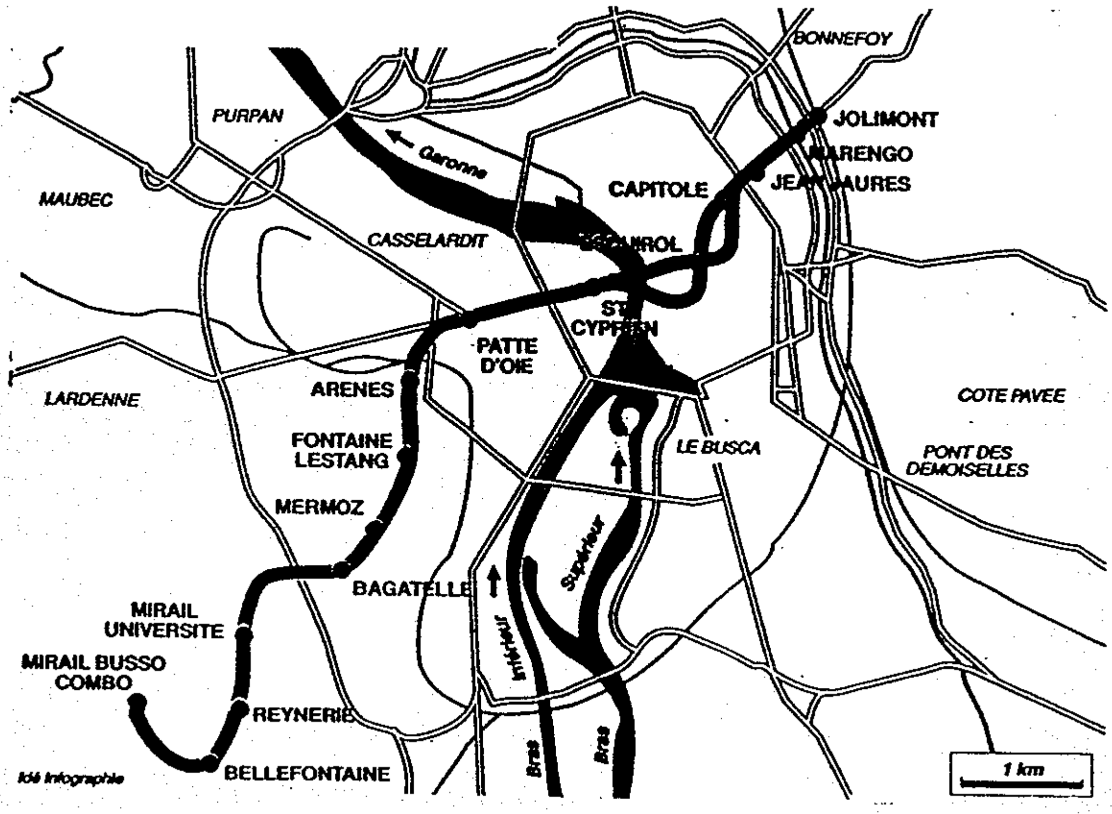

Fig 2 : Toulouse Metro

- mass transit lines, which are now built in already existing subway networks, and which will coexist with more conventional lines. This is the case of the Lyons' Metro Line 4 (MAGGALY system) and of the future METEOR Line of the PARIS Metro,

- small size systems which are represented by the Laon POMA cable system and by the SK system which is operated on a short line in an exhibition zone near Paris.

The VAL Line 1 in Lille (Fig. 1) opened the way to unmanned operation in France, due to its attractive operational characteristics :

- high commercial speed : 34 km/h ;
- short headways, currently of 72 seconds at morning and evening peak hours, with a maximum of 6 min. at night and early in the morning ;
- high availability, already higher than 0,98 just after the opening, and now currently over 0,995 ;
- perfect safety of operation ;
- good accessibility, particularly for handicapped people ;
- good acceptance by the users.

These qualities, and its transport capacity up to 10 000 pass/h/direction with a two vehicles consist, make this system well adapted to medium size cities, and it has been already adopted by Toulouse (550 000 inhabitants) (Fig. 2) and Bordeaux (650 000 inhabitants)., as well as for linking the Orly Southern Airport of Paris to a regional metro line.

The Lyons' MAGGALY Line will mark a new step in this field, with the first application in France of unmanned operation to a new line of an already existing metro network, and to large capacity trains.

This evolution will continue with the high capacity METEOR Line of Paris Metro.

The table of Fig. 3 presents the main characteristics of all these systems. We will concentrate in the following on the two first categories mentioned above, light rail and mass transit systems.

Fig. 3 : Unmanned Urban Transportation Systems in France

LINE	Opening date	Length (km)	Number of stations	Number of trains	Number of veh/train	Vehicle capacity	Interval	
							min.	max.
Lille VAL Line 1	1983	13,3	18	54	2	80	72 s*	6 min
Lille VAL Line 1 bis	1989	12	18	29	2	80	2 min*	6 min
Laon POMA	1988	1,5	3	3	1	40	2,5 min	
Lyon Line 4 (MAGGALY)	1991	13	13	36	2 or 4	130	90 s	
ORLY VAL	1991	7	4	8	2	80	4 min	15 min
Toulouse VAL Line 1	1993	10	15	24	2	"	80 s	6 min
Bordeaux VAL Line A + B	1996	12	18		2	"		
Lille VAL Line 2	1994-99	20	25	60	2	"		
METEOR	1996	9,6	10	23	6	118		

* actual values - a minimum interval of 60 sec is possible

2- The main technical evolutions of the French unmanned systems :

Let us remind that the first line of the VAL system, the Lille Metro Line n° 1, was characterised by the following features :

- safety electronic equipments based on a "fail-safe" technology,
- fixed-block automatic protection system,
- platform protection by platform doors.

All the lines from the VAL family which have been opened up to now or are under construction in France present the same features.

There has been however some evolutions on these different points in the family of mass transit systems, which will be briefly reviewed hereunder.

2.1. - Use of microprocessors for safety functions :

The use of microprocessors in safety functions has been avoided up to a recent period due to the difficulty for demonstrating the safety of such equipments.

At the beginning of the eighties, the Paris Metro Authority, RATP, decided to develop a new control system, called SACEM, for its regional network, the RER, in order to enhance the capacity of the lines ; this new system required the extinction of the wayside signals, and the use of a cab-signal involving safe track-vehicles transmissions and a safe computation of the stopping distances on board the trains.

For these safety functions, after a preliminary work conducted at the beginning of the eighties with the French Railways (SNCF) on different micro-processors safety architectures, RATP has promoted the development of an architecture conceived initially by MATRA-TRANSPORT and based on a single microprocessor protected by data coding, called "vital coded monoprocessor" (1) (2).

The main interests of this architecture are that :

- it allows a mathematical safety demonstration, and a rigorous evaluation of the safety level of the hardware,
- it may use without particular caution any commercially available microprocessor,
- it affords a good protection against the eventual defects of the compiler and other development tools associated with the microprocessor.

The design of this architecture is based on the consideration that an error in a computer processing may always be related to an error on an operand, an operator or an operation.

- operation errors, which result in wrong values of a variable, may be dealt with by data coding.

- operand and operators errors may be dealt with by a signature concept.

The code which is used to protect the data processing against computation errors or against an alteration of the value of the variables is an arithmetic code based on the following principles : each variable x is represented by a coded value X containing a functional part of N_f bits and a coded part of N_c bits. The total field of the variable X contains $2^{N_f + N_c}$ values, among which only 2^{N_f} correspond to the possible functional values and the probability of an error being non detected is equal to :

$$\frac{2^{N_f}}{2^{N_f+N_c}} = \frac{1}{2^{N_c}}$$

and it may be adjusted to the wanted degree of safety.

To realize this coding, a prime number A of the order of the 2^{N_c} is choosen, as well as an integer k such as $2^k > A$ with $2^k = q_k A + r_k$.

Suppose that the value x to be coded is such that :

$$x = q_x A + r_x$$

Then :

$$2^k x \text{ (modulo A)} = r_k r_x = r_{kx} \quad \text{with} \quad r_{kx} < A$$

The coding consists in representing each variable x by a variable $X = 2^k x - r_{kx}$ which is divisible by A and in which the functional value x, which occupies the higher order bits, with rank $\geq$ k, and the coded part $-r_{kx}$, which occupies the lower order bits, with rank < k are separated.

The protection against errors affecting operands or operators is ensured by a concept of signature, which consists in affecting to each coded variable a predeterminated value $B_x < A$, choosen randomly, and characteristic of the identity of x,-but independent of its value. Furthermore, to avoid errors in the updating of the variables, a date D, representative of the number of the current execution cycle is added to the coded part.

Finally a variable x is represented by a coded value :

$$X = \underbrace{2^k x}_{\text{functional part}} - \underbrace{r_{kx} + B_x + D}_{\text{coded part}}$$

Each arithmetic or logic operation envisaged on functional variables like x are transformed in a so-called "coded operation" which works simultaneously on the functional part and on the coded part of the variable.

For instance, at the arithmetic addition $z = x + y$ corresponds a "coded addition" which leads to a value

$$Z = 2^k z - r_{kz} + B_z + D$$

$$\text{where } z = x + y$$

$$r_{kz} = r_{kx} + r_{ky}$$

$$B_z = B_x + B_y$$

In a multiplication, the signature processing is less straightforward, but leads to a signature

$$B_z = K.B_x B_y.$$

Some complementary precautions are provided in cases of branches or loops to check the good execution of these instructions, and to propagate correctly the signatures.

This type of coding is well adapted to railways applications, in which the safety functions are called cyclically and lead always to the same command, to stop the train, if something is going wrong, and consequently to the same signature.

In the processor, the program is designed to process in parallel the functional parts and the coded parts of the variables, in order to elaborate at the end of the cycle the outputs which will command the actuators, and the corresponding signatures which are checked against a predetermined value in a fail-safe "dynamic checker" which commands automatically the emergency braking in case of a discrepancy between a computed and an expected signature (fig. 4).

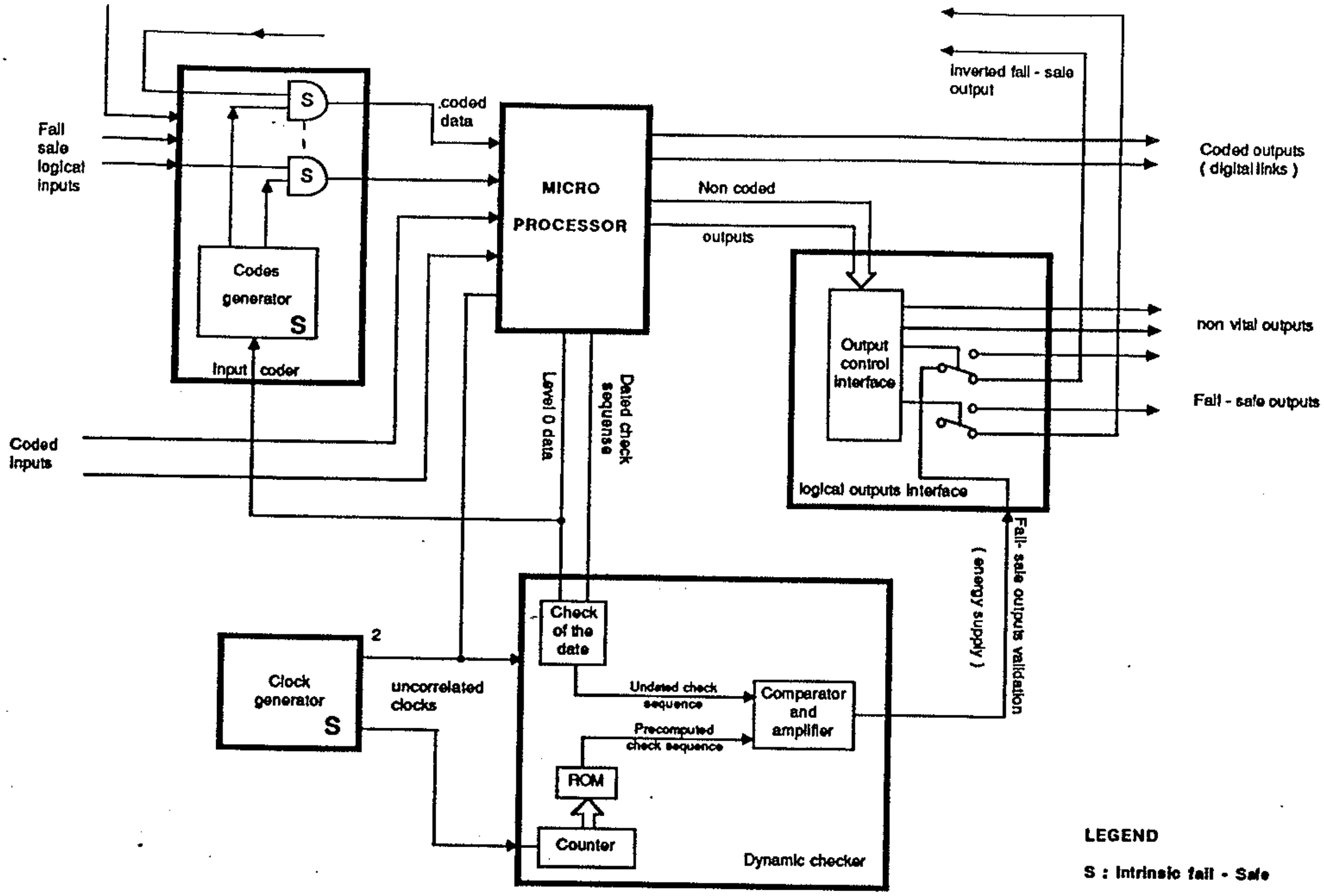

Fig 4 : Vital coded monoprocessor - Hardware organization (Source : (2))

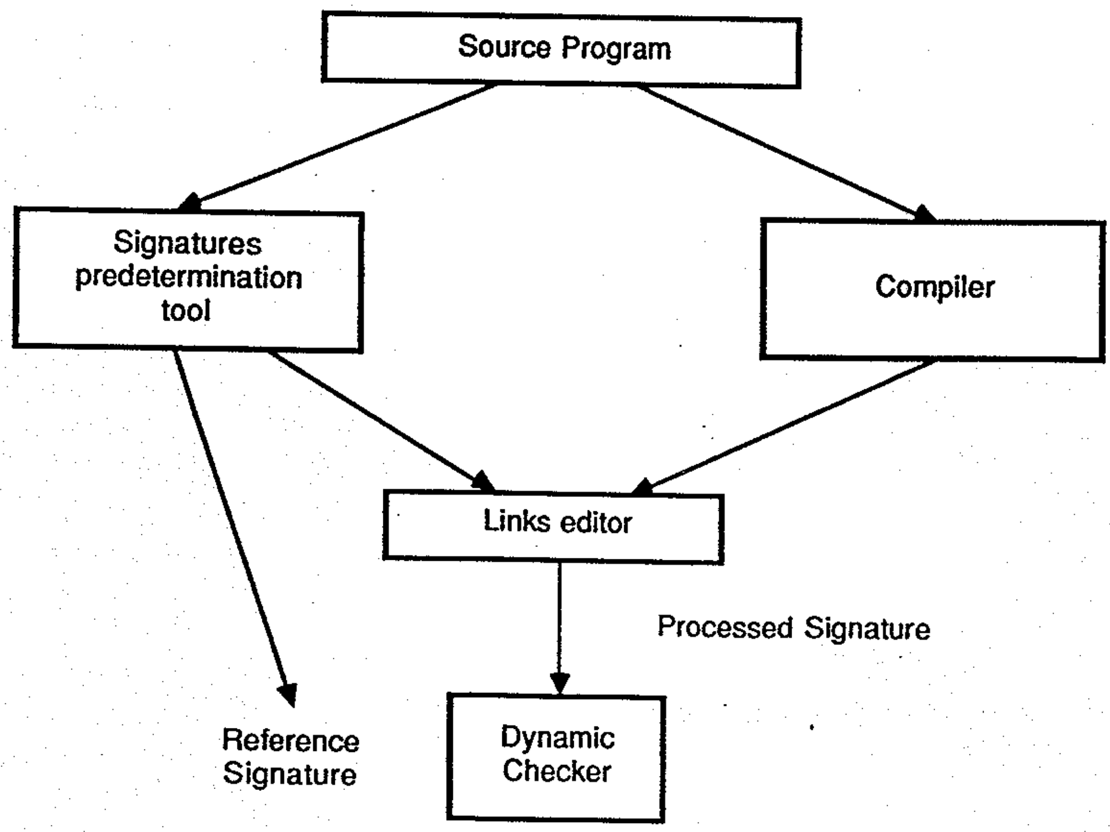

Fig 5 - Vital coded monoprocessor.Software organization (Source : (1))

The program code is elaborated, starting from a source program, through two different channels : a compiler which deals with the functional part of the program and a tool for the predetermination of the signatures, as illustrated Fig. 5.

For the design of the safety application software, a rigorous methodology was applied, based on :

- a formal automata specification method derived from SADT (Structural Analysis and Design Technics) principles, and supported by specific software tools,
- formal proof applied to the most critical software modules, based on the so-called "B" method,
- test generation tools,
- complexity analysis.

This new "vital coded microprocessor" architecture is now a standard for safety realizations in ground transportation in France, and has been already used on Paris RER Line A, on Laon POMA, and on Lyons' MAGGALY system, as well as on the Chicago Airport's VAL Line.

2.2. - Development of a moving block Automatic Train Protection (ATP) system :

The first experiments with a moving block ATP began in France in the middle of the seventies with the implementation in Orly Airport of a test track for the first generation of the ARAMIS system, a system designed for the operation of trains with variables lengths consisting in vehicles electronically coupled through ultrasonic and optic sensors.

A second experiment, with a second generation of this system took place on another test track in Paris in the years 1982-86 but the project of building an operational line was abandoned for financial and commercial reasons.

The decision of converting the 4th Lyons' Metro Line under construction to unmanned operation, under the name of MAGGALY, was taken during this same period (3) and Lyons' Authorities decided to adopt a moving block ATP in order to obtain a better flexibility of operation : a study conducted in Lyons in 1987 had shown that the possibility of operating variable size trains according to the time of the day, and to automatically achieve train separation in the train storage area could lead to significant savings, in the order of 3 MF/year, in electric energy and in maintenance (4).

The ATO-ATP system which is implemented in Lyons' MAGGALY Line is based on a division of the line into "sections" of a length between 1 to 2 km, comprising 1 to 2 stations.

Each section (Fig. 6) is controlled by a fixed track-unit which is linked to the centre of operations, to the adjacent track-units, to the stations safety equipments, to the switching and signalisation equipments, and to a track-vehicles transmission set layed down along the track, and consisting in :

- two inductive loops working in redundancy for the reception of messages sent by the trains - These loops are regularly transposed in order to reduce diaphony effects,
- one inductive loop used for the transmission of messages from track to trains and also for train location.

To realise this location function, this transmission loop is fitted at intervals of around 50 m with specific transpositions forming a code, and used as beacons for the absolute or the relative positioning of the trains inside a section.

Each track-unit has in charge the tracking of the trains in its section, and the transmission to each train of informations concerning the track geometry, the speed limits, the track occupancy and the state of the switches in front of it. To fulfil its tracking function, the track-unit interrogates at regular time intervals all the trains of its section in order to receive from them their position and speed data.

Each train is equipped with an on-board control unit having the following tasks :

. computation of the position and of the speed of the train, starting from the informations given by the beacons, and from measures given by on-board odometers,
. computation of an authorised speed based on the data received from the track-unit and from data stored in its memory,
. comparison of the actual speed with the authorised speed, and eventual elaboration of emergency braking commands.

All these ATP train and track controllers are safety equipments based on the vital coded microprocessor already described.

This new form of ATP which will be put in operation in 1992 on the MAGGALY Line will certainly influence the evolution of the future generations of unmanned systems in France.

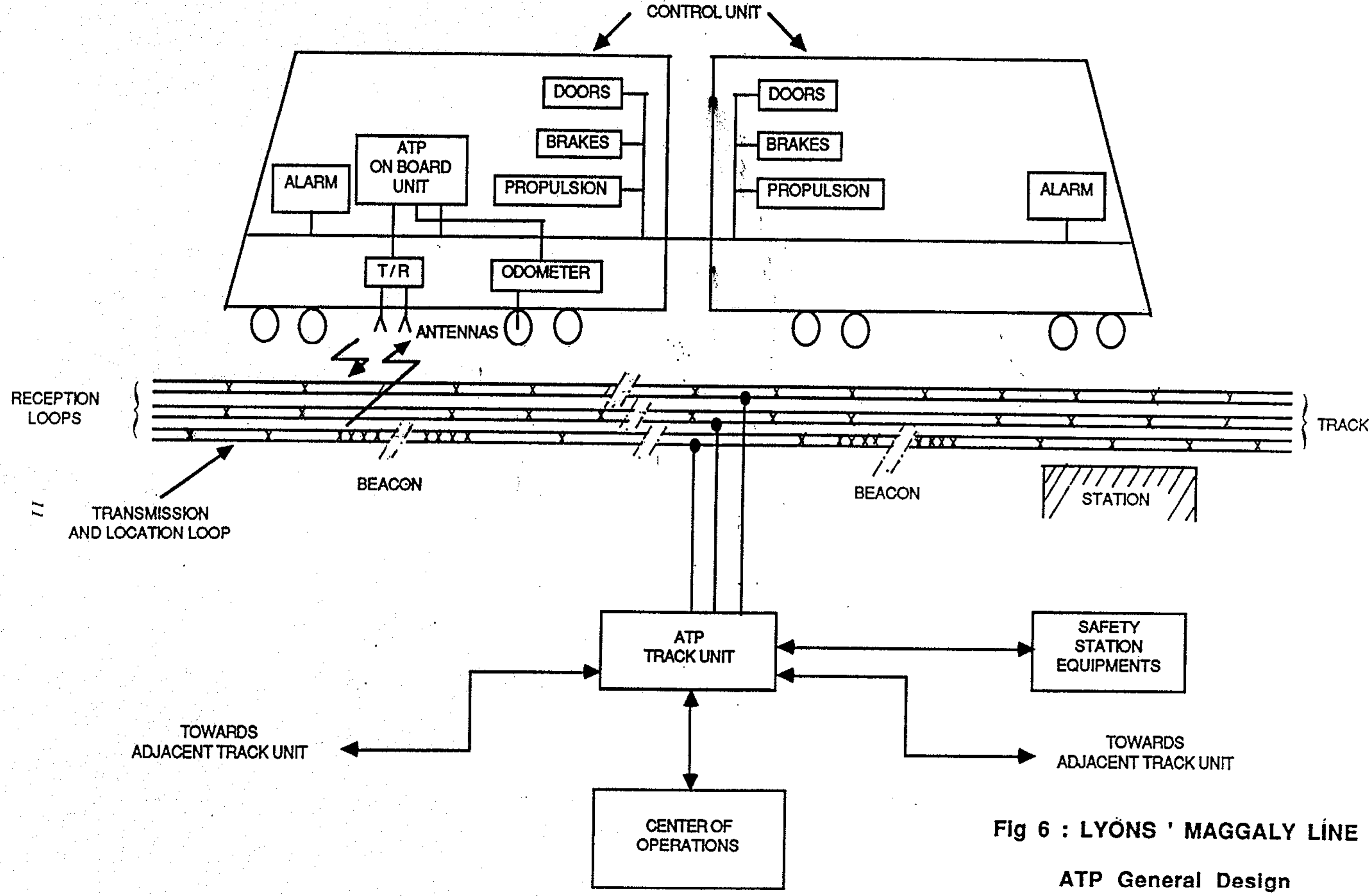

Fig 6 : LYÖNS ' MAGGALY LİNE

ATP General Design

2.3. - Platform doors :

The introduction of the moving block principle is not the single originality of Lyons' MAGGALY Line which is also :

- the first fully automated line built in France as part of an already existing conventional Metro network,

- the first fully automated line of an important transit system built in France without platform doors.

Since the opening of the first VAL Line in Lille in 1983, the use of platform doors is considered in France as the most efficient way for preventing accidents at the interface between vehicles and passengers and it is generally a recommended practice, except for very light systems like the Laon's Poma cable car.

The Lyons' Line 4 having been designed and partially built before the decision of converting it to unmanned operation, the installation of platform doors in the stations raised some technical difficulties. It was consequently decided to dispense this line with the compliance of being equipped with platform doors, provided that a sufficient protection at least equal to the protection offered by a driver should be granted to the passengers :

- against the risk of being dragged by a starting vehicle, through the use of sensitive vehicle door closure,

- against the consequence of a passenger's fall on the tracks : to detect such a fall, a first solution, based on TV image processing was experimented in Lyons in 1987, but did not give satisfactory results. Finally a more conventional method based on a double barrier of infrared beams, regularly spaced with 15 cm intervals, layed down above the tracks was adopted (5).

2.4. - Other technical evolutions :

In complement to these three main innovations concerning the "system" aspect of the lines under consideration, a number of other technical evolutions in the design of the vehicules or of the ground equipments have been introduced, for instance :

- the use on VAL Line 2 of :

. electric vehicle doors instead of the pneumatic ones installed on the Lille VAL Line 1,

. GTO thyristors in the power control equipment,

. optic fiber in ground transmissions,

- the use on MAGGALY Line of :

. automatic coupling/uncoupling of trains,

. a new designed control centre for all Lyons' Metro network equipped with workstations connected to a LAN (Local Area Network), and with video projectors which substitute to conventional wall displays.

3 - Perspectives of evolution of unmanned systems for the future :

We have just seen some evolutions of unmanned systems technology during the last 10 years. This evolution process will continue under the pressure for public transports to be more and more cost effective.

3.1. - Short term evolution :

Among the main potential evolutions in the field of automatic train control which can be predicted for a relatively short term, we can mention four domains :

3.1.1. - The development of automatic diagnosis and maintenance devices for improving the reliability of the transit systems and perhaps alleviating the maintenance manpower.

A number of research and development operations have been conducted in France in this field since the end of the seventies by the Paris Metro Authority (RATP) which has developed different tools with a progressive introduction of expert systems methodology, for instance :

- a DAM (Diagnostic and Maintenance Aid) for the ATO equipments of its MF 77 trains, involving specific microprocessors on train and track-units for the recording of anomalous situations, and a microwave link between track and train in each station ;

- a SIAD (Integrated Data Acquisition System), for the data recording and the automatic diagnosis of the power control units of the MI 84 trains (6) ;

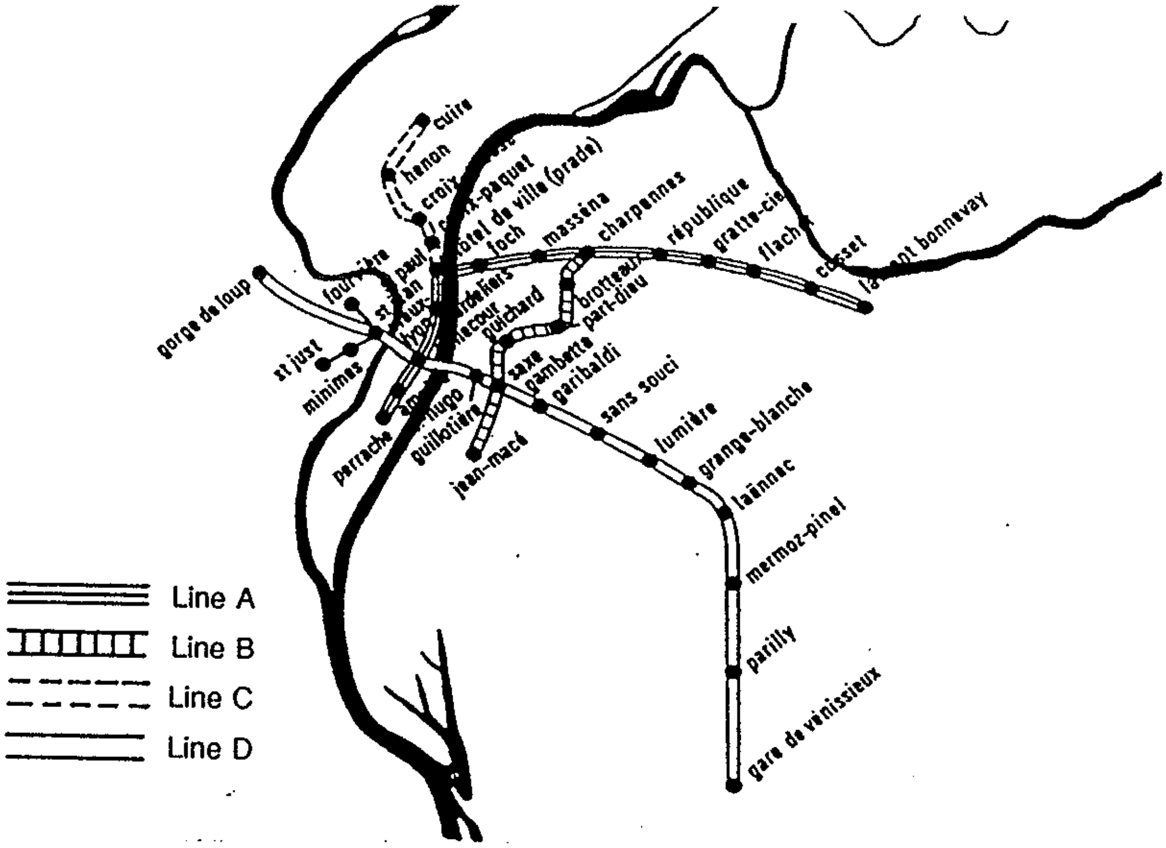

Fig. 7 : Lyons' metro network with MAGGALY Line

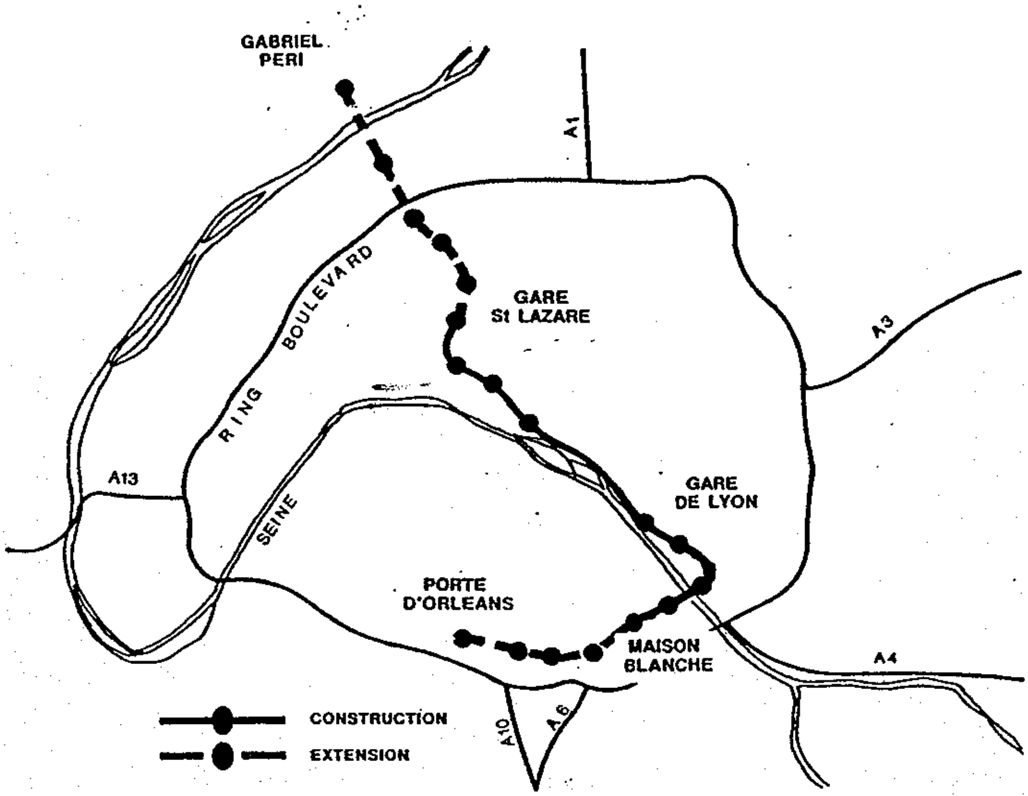

Fig. 8 : Paris METEOR Line

- a diagnostic and maintenance tool specifically designed for the SACEM ATP system installed on the Paris RER Line A, already mentioned (in § 2.1.) ;

- some other diagnostic tools, like TRUC (Transmission of Useful Information to the driver) to assist a driver in the diagnosis of a train failure, or like MARSTEL (Aid to the Resolution of Defect Signalisation by Telephone) which uses the telephone network and MINITEL terminals for the monitoring of fixed installations in the station.

It may be mentioned finally that other Metro Authorities, in Lyons and Marseilles have also realized their own diagnosis and maintenance facilities.

This kind of facilities will continue to be developed in the future particularly for unmanned systems.

3.1.2. - The enhancement of the capacity of track-vehicles transmissions to allow :

- an increase of the volume of data transmitted from the vehicles to the ground for diagnosis purposes ;

- the possibility of sending TV images from vehicles towards a centre of operation to improve the surveillance of the inside of the vehicles or the surveillance of the track in front of the trains : the remote monitoring of the passengers compartments is already required in some new transportation systems in development like METEOR.

Microwaves offer good potentialities for the establishment of such transmission links.

A first application in the form of local transceivers for the transmission of diagnostic data in the terminals or in the station of Paris Metro has already been mentioned in § 3.1.1.

A lot of developments are underway in France on continuous data transmission links between track and trains based :

- either on the natural propagation of microwaves in tunnels (7) : theoretical researches as well as experimentations in different kinds of tunnels have demonstrated the feasibility of data as well as of images transmission between ground and trains at frequencies of around 10 GHz over distances in the order of a metro insterstation length ;

- either through a slotted waveguide (8) : a system called IAGO allowing high capacity transmissions between vehicles and track, as well as vehicle positioning, based on a slotted waveguide working at a frequency around 2,5 GHz has been developed in France in collaboration between

GECALSTHOM, INRETS and Lille University, and is now proposed for new metro lines.

3.1.3. - Development of more efficient tools for the design and validation of safety software :

One of the main reasons for the relatively slow introduction of microprocessors in ATC safety functions is the great difficulty of proving the correctness of the software.

Although a number of tools and methods are already available to improve the realization of reliable software, it is still impossible to demonstrate completely that a program comprising over some hundreds instructions does not contain any fault.

This problem, which does not interest only the transportation domain, but almost all the industrial domains, is now dealt with in a number of University Laboratories, and it may be expected that new tools will be developed :

- in the field of formal specification and formal proof of software modules ;
- in the automation of the passage from a formal specification to a machine code ;
- for the automatic generation of validation test scenarios.

3.1.4. - The development of more flexible modes of operation :

It has already been mentioned in § 2.2. that the operation of trains with a number of coaches varying with the time of the day could lead to significant energy and maintenance savings.

This "temporal" flexibility which is already applied in a number of mass transit networks, whether manned or unmanned, may be completed by a "spatial" flexibility consisting in the operation of fully automated train with a number of coaches varying along a line : the reference (9) shows that this kind of flexibility may lead to important investment savings.

Moreover, full automation may allow the operation of specific configurations like single-track lines, which are not so developed now, and which require a very rigorous synchronisation of the movements of trains.

3.2. - Perspectives of evolution for a longer term :

For a longer term, some other perspectives of evolution of unmanned transit systems may be envisaged, considering some present developments in neighbouring domains.

3.2.1. - The researches led by different railways administrations in USA as well as in Japan or in Europe for the development of so-called "Advanced Trains Controlled Systems " (ATCS in USA, ASTREE in France, LZB in Germany, etc ...) based on the concentration of intelligence on board the trains, and on a minimisation of track equipments, could have some influence on the extension of unmanned operation to suburban or regional mass transit lines.

Such control systems should be probably better adapted to the operation of these lines for which the present fully automated control systems developed for urban lines with high frequencies would probably be not sufficiently cost effective (10).

3.2.2. - Many researches are now underway through the world on the development of electronic driving aids for road vehicles :

- AMTICS-RACS programme in Japan,
- IVHS (Intelligent Vehicle Highway System) programme in USA,
- EUREKA-PROMETHEUS programme in Europe.

Among the subjects covered by these programmes, some of them tend towards the development of "cooperative driving" equipments which could substitute partially the driver. These developments involve the realization of new sensors for the automatic monitoring of the car environment :

- anticollision radars,
- TV image processing.

All these equipments will initially be very expensive, and before installing them in cars, a first application step could consist in experimenting them on mass transit systems.

These developments could offer the possibility of operating unmanned transit systems on non-fully separated tracks, for instance for crossing some street intersections at surface level. Such a possibility could alleviate significantly the infrastructure costs of these systems.

4 - Conclusion

Although unmanned operation seems now to be well established in a number of countries, and unmanned systems work already very satisfactorily, these systems will continue to meet substantial evolutions in the future :

- either for reducing their cost,
- either for integrating new technics and new components,
- or for extending their domain of application.

It will be very exciting to follow all these evolutions in the coming years.

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