all eight wheels (for a 24.9 m car) motored and steered by the articulations. This is based on a four-axle articulated tram delivered in 1966 to Bern which had the single axle trucks successfully steered by the articulations. The motors will be fully suspended from the body frame.

As the designs 3.2 to 3.4 will start running in 1993/94, only from 1995/96 onwards will one be able to judge their performance, wear and tear and noise levels That will be the moment, that a more complete judgment of this development will be possible.

4. The price development.

The price consequences of this development are as dramatic as the design changes. The price of a German low-floor bus (11.8 m x 2.5 m) is around 13,400 DM/m^2, 1988/89 tram prices were around DM 33,000/m^2, at that time 2.7 times the price of a standard low-floor bus. Now low-floor tram prices range from 42,700 till 60,000 DM/m^2 or between 3.2 and 4.5 times the price of a bus/m^2. Even if the tram has a write-off period which is generally twice as long as the bus (25 years), this makes the tram comparatively expensive and its role should therefore really be confined to systems which carry a considerable passenger load, say not below 12,000 - 16,000 passengers/direction/day/line i.o. to arrive at a reasonably acceptable cost/passenger km. This point should be seriously weighed when considering the well known specific advantages of electrically driven, guided public transportation systems.

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VAL Automated Guided Transit Characteristics and Evolutions

1998

Regis Lardennois

VAL (Light Automated Vehicle) is a medium capacity driverless automated guideway transit system. It has demonstrated both technical feasibility and economical performance of driverless operation applied to a metro line.

It includes several advanced well proven technologies. Since the first line design, the product has been adapted to various operating requirements and enhanced by application of further technological evolutions in several areas: Automatic Train Control, Rolling Stock, Track.

Introduction

The first VAL line is in commercial use since 1983 and a total of 4 lines are in operation:

- Lille line 1 (France),	8.3 miles, 38 vehicles	1983 - 1st section 1985 - 2nd section
- Lille line 2	7.5 miles, 43 vehicles	1989
- Jacksonville, Florida	0.6 mile, 2 vehicles	1990
- ORLY Airport	5 miles, 8 vehicles	1991

and construction of three more lines will be completed within the end of 1993:

- Chicago O'Hare internal airport transit,	3.1 miles	13 vehicles	1992
- Taipei,	6.7 miles	102 cars	1993
- Toulouse (France)	6.2 miles	29 vehicles	1993

The first 4 lines have safely transported over 300 million passengers.

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General Description of VAL System

Operation

The VAL system is designed for a high operation speed (34 km/h) and headway as short as 60 seconds (with a 25s dwell time).

On most applications, platform doors ensure passengers comfort and safety. See Figure 1.

Central supervision with extensive data acquisition ensures a high level of availability. In Lille, the probability for a passenger being delayed over 4 minutes is 0.002.

Fully automated vehicle and stations operations reduce costs and allow a high flexibility in transit offer:

- In case of an unexpected passenger rush, it is possible to insert several trains on the line with a delay of only a few minutes.
- It is economically possible to keep a short headway (about 3 minutes) during the off-peak periods.

Figure 1. VAL platform doors.

Technologies involved

Specific technologies are as follows:

- Automatic Train Control (ATC).

VAL ATC has a specific design the challenge of which is to ensure:

- a high level of performance (high commercial speed, short headways),
- a high level of safety,
- an excellent operational availability,

with the use of proven electronic technologies and redundancies for key functions.

The design of Automatic Train Protection (ATP) is oriented to apply analog or discrete electronic components for key functions such as vital transmissions and logics. Train speed programs are defined by the position of wire pairs crossings in a medium frequency transmission support into the track.

In this transmission system, vital functions are ensured by:

- carrier sensing,
- transmission of logical orders by 5 sub-carriers, generated and filtered by tuning forks,
- phase sensing in order to detect wire crossing.

Other functions are performed by using the same transmission support inside the track:

- telemetry - remote control,
- voice communication between trains and wayside equipment.

All logical vital functions use hybrid thin film fail-safe modules. On board non-vital control functions are supported by microprocessors.

ATC performs the VAL system's specific function:

- safe platform door control,
- a very accurate station stop in relation with platform doors width,
- capability to stop safely all vehicles on a section of the line, and removing traction current by simply holding an emergency handle in any vehicle. This function is highly critical

to the availability point of view.

- VAL train detection

The principle of train detection is shown in figure 2. It uses:

- negative detection of any train at the limits of zones corresponding to each wayside equipment, using the occultation of an ultrasonic or infra-red beam modulated at 34 kHz,
- trains emission of carriers into the transmission line,
- tracking of trains using a vital logic. This logic is fully fail-safe and detects any failure in the transmission system. This characteristic is used for the emergency evacuation function. In case of emergency, passengers may pull an emergency handle that breaks the power supply of on-board antennas. This situation is detected by wayside equipment that releases the emergency braking of all trains on the section and opens traction power breakers in the power substations.

- Compact vehicle. See figure 3.

Thanks to a high frequency, 26 meter-long VAL trains offer a capacity of 12,000 passengers/h. This substantially reduces the cost of station civil works. The width of the vehicle is limited to 2.06 m. in order to reduce tunnel construction works cost.

Vehicle propulsion is ensured by two 150 kW DC motor mounted under the car body. These motors are controlled by a chopper and each motor drives a single steerable axle.

- Rubber tired wheels.

VAL vehicles use pneumatic rubber tired wheels, steered by guidance wheels rolling on lateral rails. This solution has many advantages:

- high traction and braking performance,
- capability to handle grades up to 10%, and small radius (30m) curves
- reduced vibration and noise, and reduced track maintenance costs,
- long tire operational life: 200,000 km,
- load up to 14 tons per axle,
- speed up to 80 km/h.

A specific track switch has been designed, using central steel

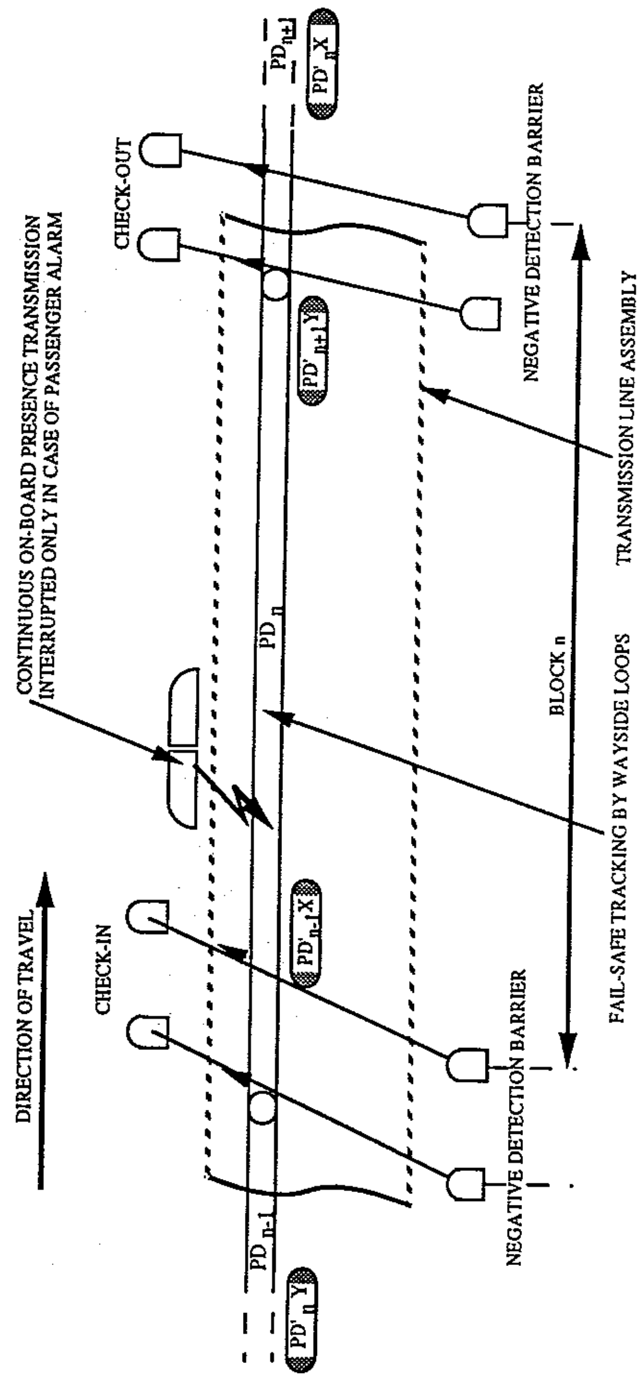

Figure 2. Train Detection System.

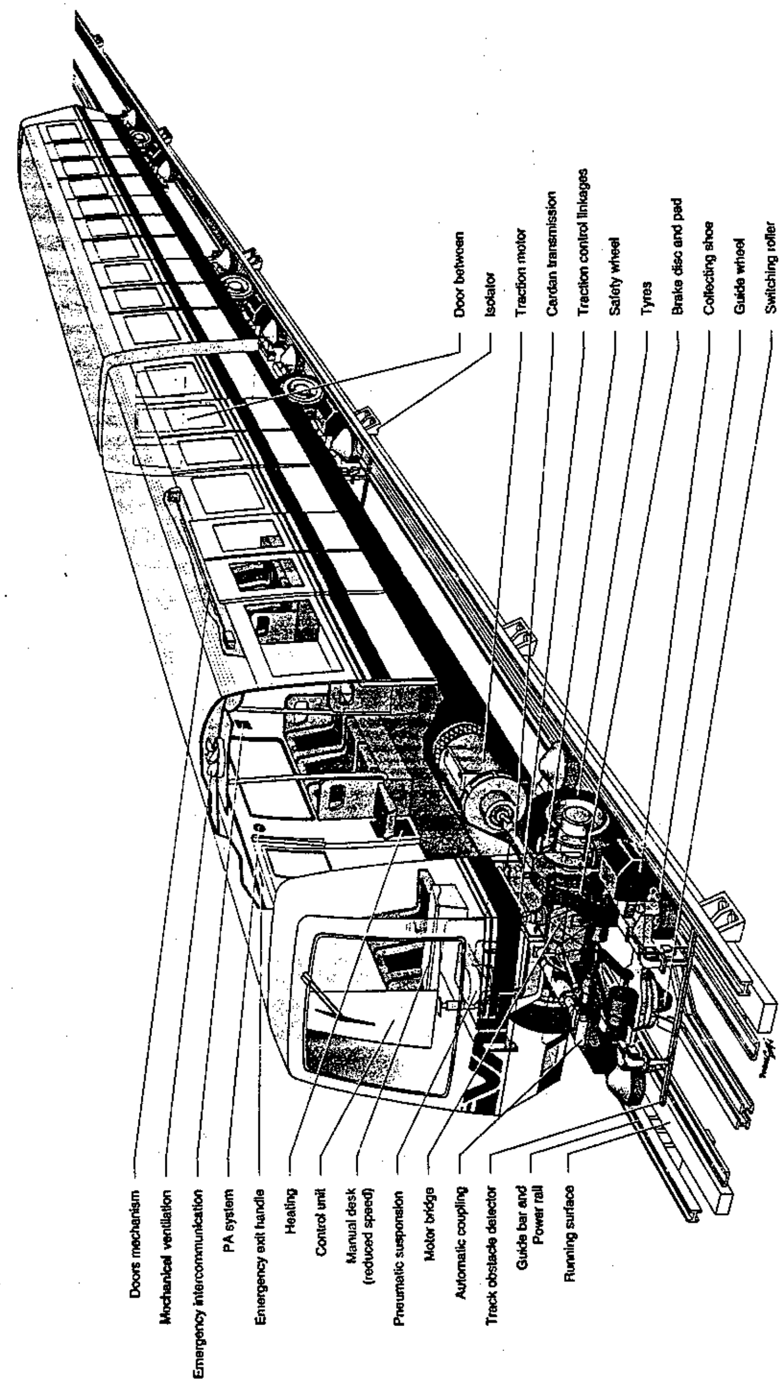

Figure 3. Vehicle Equipment Layout VAL 206, Lille (France).

wheels mounted on each bogie.

- Extensive supervision and telemetry.

This point relates to security, safety and reliability. Closed circuit television in stations and two way communication with stations and trains are used to connect with central control. In the event of an emergency of any kind, supervisors can instantly evaluate the nature of the situation and dispatch appropriate assistance. Additionally, for security and reliability purposes, all major components are monitored at central control so the status of subsystems such as vehicle running gear, wayside equipment, platform doors, ticket vending machines, etc. are permanently monitored.

The Economics of VAL Operation

As developed for VAL, automation not only means driverless operation and high frequency at low labor operation costs, but also a fully developed ATS with fully monitored systems resulting in considerable savings in maintenance costs.

It is the combination of low operating costs, increased ridership and state-of-the-art maintenance facilities and procedures that make the economics of VAL operation unique in the transit industry today.

Total 1988 staff for Lille line no. 1 was as follows:

1.	Central control		28
2.	Maintenance		
	Rolling stock	31	
	Fixed system equipment	18	
	Track and building	24	
	Fare collection system	3	
	Management	9	
	Total maintenance		85
3.	Roving team		10
4.	Ticket control, passenger information and fare collection operation		34
5.	Administration and management		26
	TOTAL 183		

A good measure of overall productivity is the ratio between total staff and number of passengers transported by year.

The VAL in Lille with a staff of 183 in 1988 and ridership of 29.4 million has reached a ratio of 160,000 passengers per employee per year, a productivity nearly twice as high as the best manually operated systems worldwide.

With the opening of Lille's second line, total length has doubled, as well as the number of stations and the fleet today represents 83 VAL 206 train sets. In other words the system size has doubled, yet total staff is only 285.

Figure 4 shows the VAL system compared to some of the best rail systems. In 1990, a total staff of 260 produced 44.2 million passenger trips i.e., a productivity of 170,000 trips per employee per year.

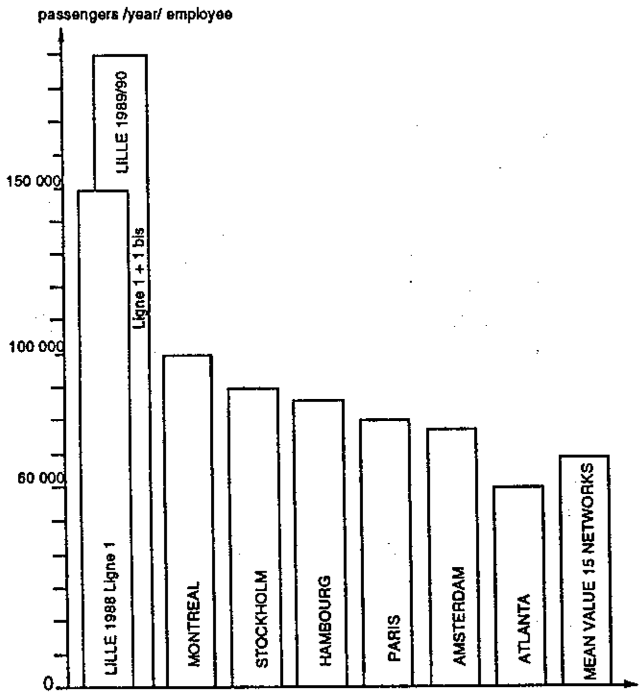

Figure 4. Labour Productivity of Various Urban Rail Networks, 1988-1990

As already mentioned, driverless operation is a source of labor cost savings: if the Lille system were manually operated, multiple shift operation would require a minimum staff of 3 operators per train set. The net savings of VAL over a driver operated system is in the order of 250 staff.

Thanks to extensive telemetry, immediate knowledge of the status of all sub-assemblies, rolling stock as well as wayside equipment, is available. This results in substantial cost savings and explains the fleet's availability.

The cost effectiveness of VAL's maintenance can also be measured. In Lille, maintenance staff required is 9.5 per million car-kilometers; the U.S. average for metro rail system is 26, in the case of the Lille light rail this ratio is 27 staff per million car-kilometers.

Recent Technical Evolutions

Since the design and construction of the first lines, the VAL had several evolutions the most significant of which are:

- functional evolutions
  - design of a new wider vehicles. The width of the first vehicle used in European projects is 2.06m, and it is called VAL 206. The new vehicle, designed for elevated open guideways and/or heavy traffic, has a 2.56 m width and is called VAL 256.
  - in order to fulfill the requirements of Chicago O'Hare's airport internal transit, that has to be operated 24 hours a day, the VAL automatic control system has been modified in order to allow operation on a single track during the maintenance of the other track equipment. Taking into account the increased complexity of the wayside interlocking logics, these logics have been programmed into vital microcomputers. In this way, most vital links between wayside ATPs and with Central Control use serial transmission.
  - the new VAL 256 vehicle may be operated simultaneously in various configurations on a same line. In Chicago O'Hare's project, vehicle configuration is 1, 2 or 3 cars depending upon the expected traffic. However, change in vehicle configuration requires a manual support for coupling or decoupling. This vehicle may be air-conditioned.

- UITP emergency evacuation

The International Public Transit Union gives recommendation for processing emergency evacuation in metro tunnels. The basis of these recommendations is that in case of fire with production of smoke, the worst place for leaving passengers is the tunnel. Indeed, there are life hazards due to suffocation, while the visibility is very low.

UITP recommends, in case an emergency stop handle is pulled by a passenger, to try to continue the trip until the next station. Two restrictive conditions have been defined in Lille application case:

- the train speed has to be maintained over 1 m/s,
- the maximum delay is 3 minutes,

to avoid an excessive deference to the application of the stop request.

If these two conditions are satisfied, the emergency handle action is differed. This new evacuation process has been implemented on the second VAL line and will be retro-fitted on the first one.

On other projects such as Chicago O'Hare, another evacuation had to be designed. The line is mainly elevated with an emergency passenger pathway on one side only, but not always on the same side. So it was decided to lock the vehicle doors that don't face the passenger pathway. It is a vital function as it is strictly prohibited to lock the doors on the emergency exit side.

- technological evolutions
  - the first DC traction chopper was thyristor driven. Since the second line, the traction chopper is GTO based.
  - the development of a vital single computer technology that is applied to Chicago O'Hare's VAL transit has to be especially mentioned. This technology developed in the course of the SACEM project (see below) has been proven. It is applied to MAGGALY and METEOR current projects.

The base of this technique is the detection of any error in vital data processing by use of check codes associated with each data. Check codes are derived from arithmetic codes, and enhanced in order to detect specific computer errors such as addressing errors, program flow errors, branch errors... The definition of check codes and safety demonstration depends mostly on computer architecture (for instance the word length) rather than hardware technology, and is therefore easier to maintain and modify.

The vital computer is of course linked to specific vital input-output and timing functions that are fully hardware oriented.

- video-monitoring of trains

In order to increase passenger safety, and improve protection against vandalism, MATRA TRANSPORT decided to develop a continuous video-monitoring of cars, by transmission of two color video pictures from each car to the central control.

A specific microwave link was designed with the capability to transmit a video channel. The range is about 800m in the worst case in a metro tunnel and up to 8km on elevated tracks, which means it is in general sufficient to place receivers in each station.

The transmission channel between trains and wayside equipment is a key technology, but it is of course necessary to equip trains with a video network, cameras and remote control, and for the wayside equipment to select the best pictures received and transmit them to the central control. This product will be used on the RATP METEOR line.

Description of VAL ATO and Relation with Other Systems

PA135: Automatic Train Protection

This is the first major product of the company, designed 20 years ago. This product has equipped more than 1,000 trains, carrying now more than 10 million passengers every day in 5 different countries. It is still in production. VAL train speed protection is closely derived from this product.

VAL: Fully-automated train operation

The general organization of VAL automatic train operation is represented in figure 5. The main elements are:

- the transmission between trains and wayside equipment, that uses carrier transmission in the range 30 kHz to 150 kHz, by magnetic coupling of on-board coils and transmission lines in the track (see figure 6). Some of the carriers are modulated directly or by subcarriers in order to provide:
  - vital transmission between the track and the trains,
  - digital transmission for regulation and central monitoring,
  - voice communication.

Vital transmission uses 3 types of information:

- carrier detection,
- subcarriers, in the range 400Hz - 700Hz, generated and detected by tuning forks,
- transmission line crossings, used for vital speed monitoring.

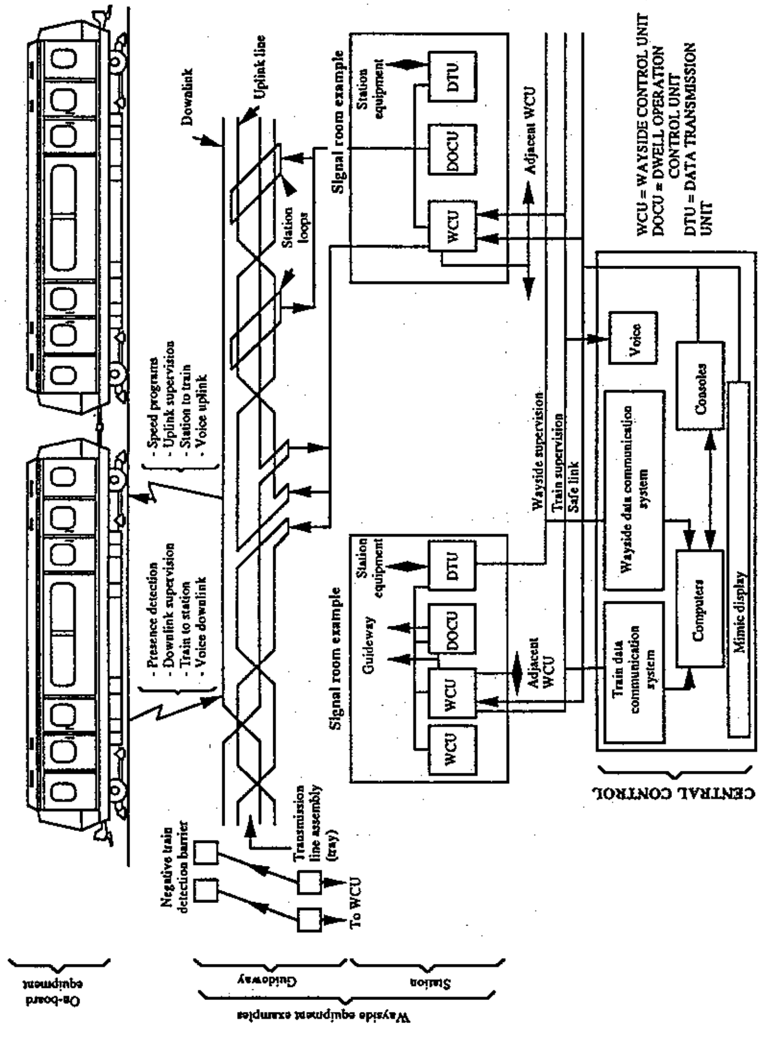

Figure 5. VAL Automatic Train Control.

and also a geographic delimitation of transmission zones by use of several transmission lines in the same support.

- the vital functions equipment, located mainly in stations and on trains, with only operator interface in the central control.
- the central monitoring equipment, providing acquisition of data from the whole system, processing them and provide the operators interface in the central control.

The practical realization of the transmission line is shown in figure 6.

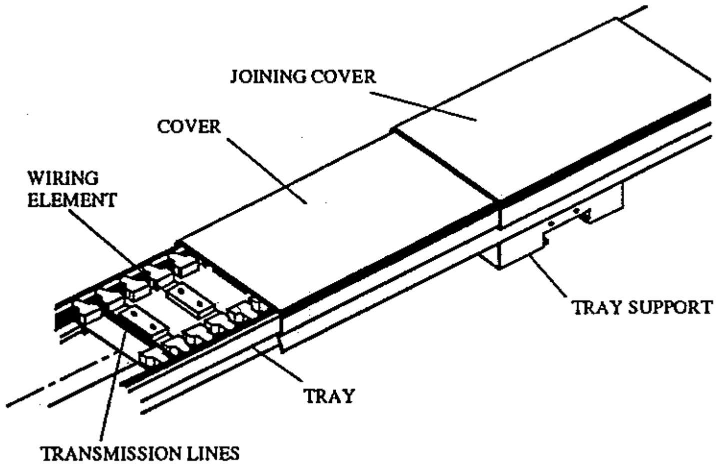

Figure 6. Typical Transmission Lines General View.

It seems interesting to list all carriers and subcarriers used in the transmission system, in order to give a view of the technical realization.

VAL Overspeed Protection

The two transmission lines used for transmission from the wayside equipment to the trains have wire crossings that define two speed programs: normal (free track), and occupied track, see figure 7.

The speed program is derived from the distance between crossings by multiplying by a reference time of approximately 0.3 seconds.

Name	Frequency	Function
Wayside to Trains		
Stopping speed program	33 kHz	Crossing on this program give the maximum speed program if the next block is occupied
Safety frequency	42 kHz	The carrier detection allows the train to move. Crossing on this program give the maximum speed program, with track free. This frequency is modulated by 5 subcarriers giving the operating mode, as follows.
Subcarriers	440,5 Hz 532,0 Hz	direction of movement
	572,0 Hz	normal mode (next block free)
	463,5 Hz	disturbed mode (next block is occupied)
	411,0 Hz	coasting mode (allows penetration in an occupied block at very low speed).
	no subcarrier	parking mode, at very low speed.
Station to trains	36 kHz	Carrier detection give the authorization to open lateral doors. Furthermore, the transmission loop is placed on the same side as the station platform. There is also a 128 bits/s digital link for the control of dwell time and door operations.
Voice link	135 kHz	This carrier is modulated in phase with a voice channel. There is also a subcarrier allowing the transmission of a 200 bits/s digital message from the central control to the trains.
Trains to Wayside		
Trains to station	56 kHz	Carrier detection by station equipment allows to open platform doors. There is also a 128 bits/s digital link for the control of dwell time and door operations.
Trains positive detection	69,4 - 70 kHz	The carrier is used for positive detection of trains. Two antennas are mounted aboard each train at each frequency in order to ensure an excellent availability.
Telemetry	80 kHz	This carrier is used for transmission of data at 400 Bits/s from the trains to the central control.
Voice link	100 kHz	This carrier is modulated in phase with a voice channel, for voice communication from the trains to the central control.

Depending upon the occupancy state of the next block on the track, the train has to comply with one speed program or with both programs. The compliance may be easily checked by measuring the time elapsed between the detection of two successive crossing on the same transmission line.

At the end of each block a "safe stopping distance", about 20m long is reserved, allowing in any case to stop a train without penetration into the next block.

The state of the next block is transmitted by the wayside equipment by the existence of a low frequency subcarrier

SACEM: Automatic train protection system and operation assistance.

SACEM is applied since 1989 on more than 200 trains of the Paris

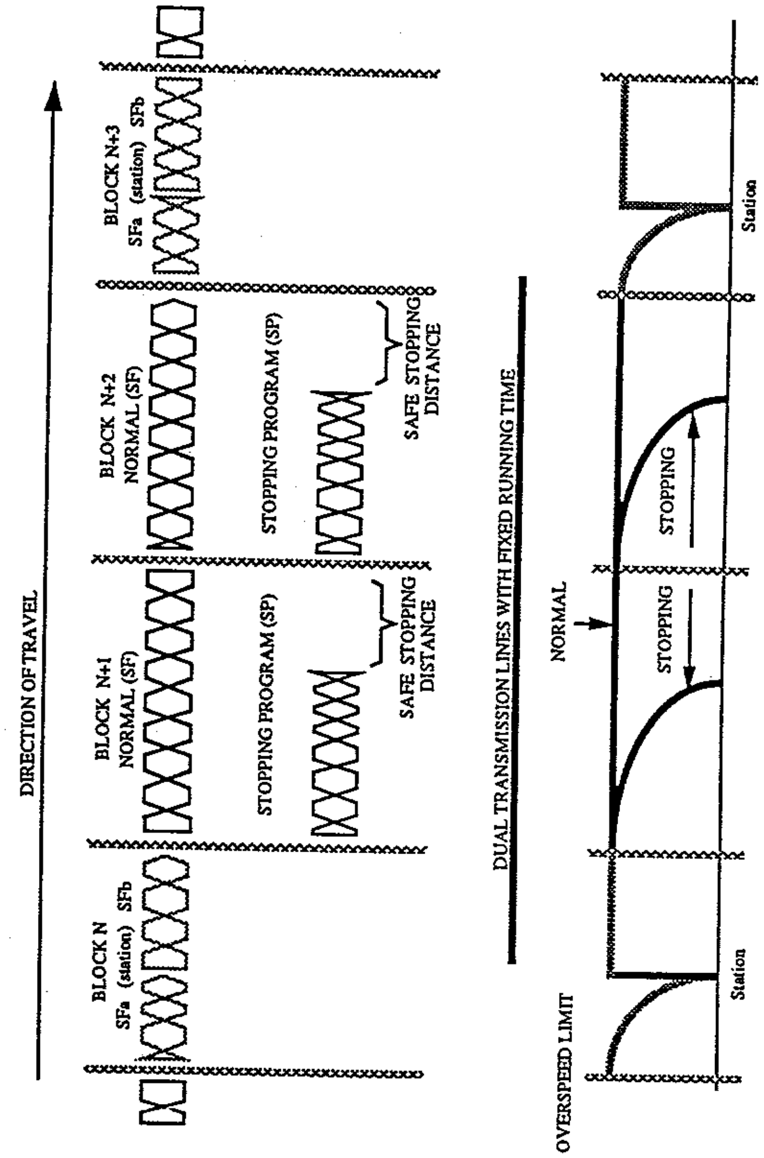

Figure 7. Normal and Stopping Speed Programs.

heavy rail A line that has the highest ridership (60,000 passengers/h/ direction) of the network. SACEM enables to reduce the headway from 2'30" to 2', with 225m steel wheel trains and a 50" dwell time. Ten years were required to design and apply advanced concepts and technologies such as:

- self localization of trains on the network,
- vital computer with a low dependency upon technology, (see above)
- vital software design,
- operation with different rolling stock on the same line.

A second SACEM line is operated since 1991 in Mexico city and new line is in the design phase for the Paris C line, operated by French Railways.

MAGGALY: Fully-automated train operation

VAL's first application success brought other projects to adopt similar concepts. MAGGALY is the first of them.

The Lyon's D line called MAGGALY design started in 1986; driverless commercial service began on August 31, 1992.

This metro uses a large profile rolling stock on pneumatic rubber tires, and requires a very high operational flexibility including for instance: single track operation, automatic coupling and uncoupling between peak and off-peak periods, that led to the design of a new type of train control based upon a moving block.

Unlike "hardware oriented" VAL train control, MAGGALY is fully "data processing" oriented. The technical features of this product are:

- each train determines it's position on the track by
  - knowing network configuration,
  - using markers inside the track for initialization and calibration
  - evaluating the distance covered by measuring the rotation of a free axle.
- each train transmits it's position to other trains via the wayside equipment which checks that all train transmissions are active.
- each train determines it's speed limit taking into account:
  - the track configuration,
  - the position of other trains,
  - it's braking capability.

METEOR: Fully-automated train operation

RATP, the Paris metro authority, has decided to create a new fully-automated metro line called METEOR. The requirements of this project are specific to the automation of existing, presently manually operated metro lines, in order to allow further application to all the Paris metro network.

RATP emphasized some aspects of operation:

- full compatibility between driverless and manually driven trains, implying a fixed block signaling,
- progressive implementation on existing lines, without service interruption.

MATRA TRANSPORT proposed a system closely derived from the MAGGALY product. The major goal is the compatibility with manually operated trains, obtained by a new concept called "virtual fixed block". It is the synthesis between:

- a "data based" design,
- a fixed block signaling (trains determine what block they occupy and transmit it to the wayside equipment).
- a performing operation, due to a small block length.

The notice to proceed was given in April 1992, and commercial operation is scheduled for 1997.

Conclusion

MATRA TRANSPORT has developed a new concept in driverless metro operation, and demonstrated its feasibility and economical performance.

The success led many transit authorities to adopt this concept, sometimes with specific requirements that involves technological changes.

The VAL evolution process is designed to give customers permanently the most efficient technology.

Glossary

DC	direct current