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TWO INTERMEDIATE SYSTEMS:

THE LIGHT RAIL AND AUTOMATIC GUIDED TRANSITS

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Urban public transport has benefited from considerable technological innovations over the past twenty years. Networks have been modernised and developed with new equipment and systems now under operation.

The quality and attractiveness of public service has been improved by these new developments. Operating conditions have been transformed, with improved safety and flexibility; adaptation to the needs of passengers and operators can be ensured owing to the possibilities offered by automation.

The evolution of urban transport is shown by the growth of systems called "intermediates" between on one hand the "heavy" systems like conventional or regional metros and on the other hand, the buses or trolley buses networks, riding at grade on a more or less separated right of way.

The rapid development of light rail and automatic guided transits has oupaced the growth of the more traditional heavy metro.

Light rail and automatic guided transit systems present intermediate characteristics between those of buses riding on shared right of way and those of conventional metros on segregated right of way, from the point of view of investment costs. Light Rail Transit (LRT) can also, more and less offer similar service and operating costs.

In this paper, it is intended to present the two types of new systems operating in France for more than ten years : light rail and automatic guided transits.

I The light rail transit

A definition of Light Rail was given in the First Report of the Light Rail Commission to the 1979 UITP Congress in Helsinki :

"Light Rail (Stadtbahn, Métro Léger) is a rail-borne form of transport which can be developed in stages from a modern tramway to a form of transport operating underground or on viaducts. Each stage of development can be the final stage, but should permit further development to the next higher stage."

This definition reflects the tendency at that time in West Germany and other continental countries to go underground with Pre-Metros in the city centre. It implies that Light Rail will go to the higher stage which, according to the definition was to run in tunnel. At present this expensive option appears to have generally been superseded. Light Rail schemes of the 1980s have shown that street operation with predominantly reserved running is both feasible and actually contributes to the humanising of the city.

In 1975, there were around 300 urban tramways networks in the world; in 1993, this had grown to more than 330 networks, and with the lines under construction (15) and planned (50) there will be over 400 networks for the year 2000.

I. 1 Infrastructures of Light Rail

Urban transit systems are better adapted than the private car to assume the larger part of urban travel, particularly commuter journeys to the city centre. As they use only a minimal area of ground for parking and maximise the capacity of the running lanes they have a smaller impact on space uptake and the environment.

However, in general traffic, particularly at peak hours, the commercial speed of urban transport is insufficient and the irregularity of passages at the stops remains one of the principal reasons of users secularisation for that type of transport. Unconstrained of the traffic hazards, the public transport systems are theoretically able to attain a commercial speed in excess of 20 km/h and regular headway times : the only disruptions arising from passenger movements at stations and queueing of public transport vehicles.

Exclusive rights of way and priority at junctions improve the quality of service and capacity of a public transport system. These parameters will depend on the type and size of the public transport vehicle, the means used to establish right of way segregation and the degree of segregation in town centres.

We present below four categories of right-of-way segregation used in the case of Light Rail :

- **exclusive right of way** corresponding in general to new realisations in city centres on several levels : tunnels or viaducts.
- **segregated right of way** corresponding to independent tracks in the middle of or along a boulevard or on a former railway track ;
- **reserved right of way** corresponding to lanes of the carriageway in general delimited by paint or using specific surfacing, but not separated physically from general traffic ;
- **shared right of way** composed of lanes of the carriageway used by general traffic : these tracks are found rather in old networks on carriageways

with little traffic or on those too narrow to reserve a suitable space for the tramway. In this last type of site, we can classify the mixed pedestrian-public transport streets or Malls in which the carriageway is used only by pedestrians and passing tramways.

I. 2 Evolution of track sites

A study made by National Institute of Research on the Transports and their Safety (INRETS) in 1987 on the theme of automation of surface transport shows that on 13 European networks with Nantes and Grenoble first lines totalling 98 lines of tramway, 34 lines have or will have in the short run percentages of networks lengths with exclusive or segregated right of way in excess of 75% of their lengths.The trend of the existing networks consists in increasing the proportion of exclusive or segregated right of way on their tramway lines.

This trend is being confirmed for the new lines, which are generally built in segregated right of way using different types of space : railway tracks, motor way bus lanes or urban streets.

Railway tracks

The use of railway tracks allows the access to the city centres without great investments in tunnels : the Tijuana and El Cajon lines San Diego, the Los Angeles-Blue line, the Calgary, Edmonton, Portland lines, the Albtalbahn to Karlsruhe, some lines of the Köln, Stuttgart, Göteborg networks are examples of this.

Motorway bus lanes

In some networks, buses use separated lanes on urban motor ways; it is sometimes feasible to use this separated lane for installing a Light Rail Transit line if traffic needs it : the cases in Los Angeles, Sacramento, Portland and San Jose are examples of this.

Rights of way on urban carriageway

As preceding, we find platforms for the Light Rail on the rapid carriageways of the suburbs, in the avenues around the centre, and in the centre by cars traffic suppressing in some streets paid up to the pedestrians and urban public transport : this is found the case of Grenoble, Berne, Bâle, Zürich 's networks in Europe, Buffalo... in the USA.

When there is no land in the centre, it becomes necessary to implement big public works by putting the tracks underground, which results in the loss of some advantages of Light Rail from the investment point of view.

I. 3 The choice of type of right of way and investment

From the above descriptions we imagine the influence of the choice of a type of a surface, underground or viaduct site of a Light Rail line part on the total investment of the Light Rail Transit system ; this choice also influences the offered capacity at peak hours.

The table below shows some costs per km of double tracks of Light Rail (without rails and energy) according to whether part of the line is on surface, underground or on viaduct.

Infrastructures	**surface**	**viaduct**	**underground**
Light Rail	22 à 55 MF	70 à 105 MF	110 à 220 MF
	4,07 à 10,2 M$ US	13 à 19,5 M$ US	20,4 à 40,8 M $US

- value on 1/1/93

1 dollar = 5,40 F on 1/1/93

I. 4 Commercial speed

The running speed for the public transport's user stays the determining factor in the choice of his new means of transport, and the priority at signalised junctions allows the commercial speed to exceed the threshold of the 20 km/h.

The commercial speed of a Light Rail is generally lower than those of an automatic Guided Transit for several reasons :

- the running time between the stops is important, the stops being closer than for a metro, the order speed (wanted speed) reached is lower than those reached on long inter station links ; the delays due to the traffic conditions like traffic jams on a shared or a poorly protected right of way , the waiting time in front of the lights at the cross-roads, the limitations of the speed due to the insertion problems of the track have a bad influence.
- the stop times in a station are most important when the platform is not at the same level as those of the floor 's vehicle, also there is a tendency to adopt for the new projects low floor vehicles (with a level around 35 cm above the

level of the rail) which makes access to the trains easier and accelerates the boarding and alighting times of passengers.

I. 5 Operating frequency and quality of service

The frequency of passage and the number of passenger places available are adapted to the need of transport : this frequency depends on several parameters such as the vehicle's monitoring speed, the braking ratio, the level of safety, the response time of the braking-acceleration system, the station , the stop time (which depends on the arrangement and width of doors, the levels of the floor and the platform, the number of boarding-alighting passengers), the random conflicts along the line which depends on the percentage of segregation of the right of way in relation to the general traffic.

This frequency also depends on the signalisation : in this matter the Light Rail is perfect hybrid between the classical streetcar operating according to street traffic rules and the classical metro operating according to the railway rules with journeys totally covered by safety signals, completed by stop devices and even by automatic driving. On the surface, the Light Rail adopts the sight seeing driving, near the cross - roads the lights are influenced or directly controlled by the trains in the frame of the priority which is generally given to them. In the underground sections, we generally use automatic block signals, completed by automatic emergency braking, devices controlling the trains going through the signals and controlling the speed, in case of a behaviour engaging the safety : there is a reduction of the flow in relation with those permitted with running at sight , this heterogeneity of flow results in an obligation to foresee regulation devices when there is a common underground section in the city centre.

Light Rail operating systems can be made with the help of operational control systems allowing postponement of departures according to frequency and to give the drivers the necessary information to regulate their speed in relation to the scheduled trip times : each vehicle sends to the central control room its position every 30 seconds which is compared on the computer with these of the theoretical schedule. The central control room says to the driver to accelerate or not, actuates the cross-roads lights to give a priority to the vehicle in relation with the delay of the vehicle. The central control room has a general knowledge of the vehicle's position in relation to the theoretical position and can speak with each driver by radio.

Thus, thanks to the separated right of way, the priority at signalised junctions, the adapted signalisation to the type of running site, Light Rail can offer a quality of service of regularity, punctuality, and safety comparable to that of the metro since the investments would be important.

Generally in France the frequency between two trains at the peak hour is 4 to 5 minutes and 7 to 10 minutes at off-peak hours but we find lower intervals around 90 seconds on St Etienne line, for example.

I. 6 Capacity

At a normal load a Light Rail vehicle carries around 175 passengers ; at peak hour, with an interval of 4 minutes the offer can be of 2625 pas./h/dir., the operation can be done by multiple units of up to 3 units what brings the capacity to 7875 pas./h/dir.

To obtain more capacity we must reduce the interval that is to say improve the signalisation, the segregation of the site in relation to the general traffic and increase the number of cars per train, thus operating with trains of 5 cars and an interval of 90 seconds running on a segregated right of way would allow a theoretical capacity around 35 000 pas./h/dir., this system would be with this right of way, this signalisation, the platform length, called a metro.

II Automatic guided transit

Automatic systems, created more recently than the Light Rail systems (first implemented in Morgantown in the USA in 1975), were, at first, limited to short distances, low speeds and low capacity services : airport, exhibitions,etc., before being used like urban transport of conventional type.

These automatic urban systems are grouped below :

- the different Japanese systems,
- the Canadian system of Union Transit Development Corporation (UTDC) under operation in Detroit, Vancouver and Scarborough (Toronto),
- the English AGT system of the Docklands in London,
- the French AGT system VAL ("Véhicule Automatique Léger"), which now has a great number of applications throughout the world,

- the Westinghouse system rather particular through having been developed to begin with mostly for airports but able to be adapted to the market of AGT (ex: Miami and Las Colinas).

Since 1981, about twenty systems of that type are under operation in actual urban centre services and numerous systems (Rennes, Bordeaux, Turin, Paris (METEOR), etc.) are planned or under construction here and there.

In all the cases, these are systems running on segregated right of way, fully automated, with quite different vehicle characteristics.

The application of fully automated driverless operation to the new transit systems is the consequence of a research of technical performances (high speeds, reducing intervals between trains, increasing safety) not possible with manually operated trains.

Indeed, at the peak hours on the urban metro of Paris and other networks in the world, most of the lines have been manually operated for twenty years yet automatically at least at peak hours, that is to say at those where operation must be the most efficient and where drivers would have to apply more concentration than humanly possible.

The user benefits from the high frequency brought by full automatism, avoiding long waiting times in station. This quality gives further attraction to public transport. In addition, this high frequency can be also obtained at off-peak hours by cutting trains between peak and off-peak hours which brings operation supplementary flexibility. High frequency of passage has another advantage on civil engineering costs of transit systems : at equal capacity the light rail (Grenoble type) running with 3 unit trains every 4 minutes offers a capacity of 7830 pas./h/dir., the AGT (VAL type) running with 1 unit train with an interval of 72 seconds offers a 8000 pas./h/dir. capacity. In the first case the platform length is 90 m, in the second case the platform length is 26 m.

In addition short headways allow the avoidance of passenger congestion in the stations and reduces the the civil engineering requirements of stations.

A further consequence of full automation and of an high frequency service is the reduction of vehicle unit capacity (the productivity of operation is not then cancelled by the increase of the number of automatic cars under operation). Reducing the size of vehicles allows for lightening of the running gear system; we can adopt, for example, a truck axle instead of the traditional bogies with 2 axles.

The integration of small size vehicles is easier in tortuous routes. Besides the size, the total weight is diminished which allows for a reduction of track civil engineering constraints.

Automation of metros would be able to satisfy the next objectives :

- reduction of investment costs,
- reduction of operating costs,
- cheaper improvements of service quality.

The innovations brought to the traditional modes of transport system have greatly spurred the improvement of the networks productivity. This evolution and the efforts of diversification of transport companies have benefited new modes of transit systems. This is to be seen in the VAL operated in Lille and Toulouse and the standard Light Rail operated in Nantes, Grenoble and Paris (St Denis) and soon in Rouen and Strasbourg whose reliability and efficiency are recognised. The rapid progress of technologies linked to the electronics and computing leads to increased gains in productivity bestowing on the public transport networks a growing tendency to automation.

Automation is only sometimes a means to satisfy clearly defined objectives. Thus on Lille's metro, automation does not come of technological futuristic feeble desires but clearly defined objectives. Since 1970 this has been to minimise the costs of a means of transport, adapted to a demand whose importance and structure normally justify a metro, all by giving to users a high service quality. These objectives have permitted to define for Lille the small gauge of VAL's system, its short passing headway at the peak hour and the technical and economical necessity to conceive its automatic integral control.

This type of driverless automation on board, has given place to particular technical solutions which would not be the same for other metros manually operated : ie. the landing doors on the platforms, the numerous redundancies of certain equipment items allowing to guaranty a very high availability without need of an immediate human intervention, the necessity to highly develop the means of monitoring and communication.

II. 1 AGT infrastructures

Segregated right of way

The public transit systems running under " automatic integral control" have several main characteristics to run on segregated right of way that is to say separated of the general traffic being underground or on a viaduct, or on the surface behind high protective fences. This stress has an incidence on investment costs because the metro is built in dense zones of cities, there are few surface sites and the number of junctions is such that it is better to adopt either a viaduct where it is possible, or an underground more or less costly in relation to the geotechnical local conditions. Then we understand all the benefits of reduced geometrical size and very short headways : a comparative analysis comparing the civil engineering costs depending on the adopted transit systems done by INRETS in 1992 allowed us to verify that the construction costs are linked to the vehicles gauge of systems and that for an equivalent capacity, the civil engineering costs (tunnel and underground stations with the cut and cover method at a superficial level) of VAL 206 is lower by 8,4% to 16,9% than these of Light Rail for 7000 to 20000 pas./h/dir. capacities, with 60 seconds headways for the VAL and 90 seconds for the Light Rail. For a deep tunnelling construction carried out with a Tunnel Boring Machine (TBM), the differences of civil engineering costs of VAL 206 and Light Rail are between 17,3 to 31,4% less for the VAL 206 at 7000 to 20000 pas./h/dir. capacities.

II. 2 Site type and investment

From different implemented projects in France we find that civil engineering costs (not including the track) are in a range of prices such as shown in the table below :

Infrastructures	**on surface**	**on viaduct**	**underground**
VAL 206	22 à 55 MF	60 à 100 MF	100 à 200 MF
	4 to 10 M$ US	11 to 18,5M$ US	18,5 to 37 M $US

cost value of 1/1/93

1 dollar US= 5,40 FF on1/1/93

II. 3 Commercial speed

Automatic guided transit can be well-adapted to the track characteristics and adopts a monitoring speed depending on the lengths of interstations, and acceleration-deceleration (tyres vehicle) allowed by the motorisation of the vehicles. The stop times in station are programmed, the dead time is suppressed, the high level commercial speed, around 35 km/h in relation to a submitted conflicts transit system, is optimised and respected. This high speed reduces the necessary number of vehicles to carry the same amount of passengers at peak hour : thus, with a 34 km/h commercial speed we must use a fleet of 34 VAL

206 rolling stock to carry 7000 pas./h/dir. on a 10 km line; with a 20 km/h commercial speed we must use 51 of Light Rail rolling stock (Grenoble type) that is to say 50% more.

II. 4 Operating headway and service quality

We saw precedently all the benefit brought by automatic integral control which allows the short passing headways and the reduced unit capacity vehicles and hence their reduced gauge. The operating headways adopted on Lille's first line are between 72 seconds (60 seconds is a possible headway) and 3 to 6 minutes at off-peak hours and by night. This short headway allows a service quality that cannot be offered by Light Rail subjected to traffic jams : thus on the Lille's network there are in the service quality indicators, one indicator of headways respect which made reference to a theoretical headway defined by a production's program, this sign makes the different number of departures with the theoretical schedule of more or less 15 seconds intervention.

The service quality in an Automatic Guided Transit, is above all, reduced waiting times and shorter running times. It also has the regularity of a metronome, and a high degree of flexibility. Thus on Lille's network, the metro makes 512 return trips by day on the first line, while a classical metro (90 seconds headway) realises 265 return trips. The VAL's waiting time at peak hour is reduced of 50% (60 seconds headway) of the metro with driver (90 seconds headway). This difference is also noticeable at off-peak or weekend hours when the VAL runs with 6 minutes maximum headways compared with 10 to 15 minutes for a metro with driver.

Automation also offers to the AGT substantial regularity; while the metro operation with a driver may be troubled by different cumulative delays, automation allows better stabilisation of the passing trains because the system prohibits a train to start before the scheduled time, it accelerates of 20 % or 33 % a train on delay, it makes easier by automatic injections of trains waiting at terminus the good cadence of all departures. We measure on VAL's operation during 99,7 % of the time a running regularity at one second near.

Automation allows for substantial adaptability ; thus when there is a drift of peak hour with abnormal crowding, a remote control signal from the central control room allows the injection of several trains without the time needed to organise drivers, oversee the staff, to plan the operating schedule,etc. The operator adapts better to the users demand, which brings to the public transport user another service quality or an extra service !

II. 5 Capacity

At a normal load a vehicle VAL 206 type carries around 160 passengers (4 pas./m^2) et 218 passengers (6 pas./m^2) at an exceptional load; at the peak hour, with a minimum headway of 60 seconds the supply can be of 9600 pas./h/dir., and increases until 19200 pas./h/dir. with a two-car train at a normal load and 26160 pas./h/dir. at an exceptional load.

At a normal load a vehicle VAL 256 type carries around 92 passengers and 132 passengers at an exceptional load; at peak hour with a minimum headway of 60 secs. the supply is 5520 pas./h/dir., if we adopt a multiple unit operation up to 4 units this supply becomes 22080 pas./h/dir. at a normal load and 31680 pas./h/dir. at an exceptional load.

III. Comparison of 2 systems : the LRT and the AGT

III. 1 Investment costs

From recent projects in France we try to evaluate investment and operating costs of each system.

The infrastructure costs vary from a project to one another. These costs depend strongly on the civil engineering importance and the underground sections included in the project. For Light Rail, costs for civil engineering, the light rail system and appended expenditure are derived from 7 schemes with a total of 59 km (double tracks) :

- the civil engineering cost is divided as below :
  . sewage, electricity, gas, telephone networks deviation,
  . concrete structures
  . the site under the tracks
  . stations
  . workshop
  . engineering
- the light rail system cost is divided as below :
  . track construction
  . energy
  . automatic vehicle location system (AVL)

. central control room (PCC)
. rolling stock

- the appended expenditure is divided as below :
  . urban environment renewal works
  . land purchase
  . project manager's expenses

Expenditures	Cost in MF & M.$ US jan. 93	Average in MF & $ US	% of total cost
Civil Engineering	34 to 102 MF 6,3 to 19M$	68 MF 13 M$	47%
Light Rail System	50 to 66 MF 9 to 12 M$	58 MF 11 M$	39%
Appended Expenditures	12,6 to 29,4 MF 2,3 to 5,4 M$	21 MF 4 M$	14%
Total	110 to 184 MF 20 to 34 M$	147 MF 28 M$	

Source : Committee Report of TCSP (Separated Right of way Public Transport) of 22/10/93.

The costs range in the chapter "Civil Engineering" can be partially explained by the most important variations seen on the concrete building (from 0 to 32 MF/km or 0 to 6M$/km) and on the workshop which is built either for the line, or the future network or merely enlarged (from 2 to 14 MF/km or 0,4 to 2,6 M$/km).

The costs range in the chapter "Light rail system" can be partially explained by the variation of the necessary supply that is to say the number of rolling stock and the electric power that must dispose the system (de 28,5 à 47,5 MF/km or 5,3 to 8,8 M$).

The costs range in the chapter "Appended expenditures" can be partially explained by the variation of the urban environment renewal works cost (from 3 to 21MF/km or 0,55 to 4 M$).

As for VAL system, 4 lines under operation totalling 42,3 km (double tracks) allows us to give the cost of civil engineering and the cost of the specific equipment linked to the integral automated system control and the rolling stock :

- the civil engineering cost is divided as below :

  . sewage, electricity, gas, telephone networks deviation,
  . concrete structures
  . site under the tracks
  . stations and the equipments not link to automation
  . workshop
  . engineering
  . urban environment renewal works
  . land purchase
  . project manager's expenses

- the transit system cost is divided as below :

  . track construction and automated system controls
  . energy
  . central control room (PCC)
  . rolling stock and the spare parts

Expenditure	Cost in MF & MUS$ janv.93	Average in MF & MUS$	Percentage of total cost
Civil Engineering	99 to 258 MF 18 to 48 MUS$	192 MF 36 MUS$	63%
Transit System	93 to 139 MF 17 to 26 MUS$	113 MF 21 MUS$	37%
Total	192 to 371 MF 36 to 69 MUS$	305 MF 57 MUS$	

Source: - " Public Transport in France ", DTT et CETUR, August 1990.
- " Analysis of trip costs : elaboration of a methodology in the frame of a transport passengers account ", CETUR et SOFRETU, February 1994.

The costs range in the chapter "Civil Engineering" can be partially explained by the percentage of underground works : thus, 2 lines which have 75% of their length in tunnel have an average cost for this chapter equal to 193 MF/km or 36 MUS$/km val.Jan.93, one line with 90% of its length has an average cost of 258 MF/km or 48 MUS$/km val Jan.93, at last one line with 40% of its length in tunnel has an average cost of 100MF/km or 19 MUS$/km val.Jan.93.

The cost range in the chapter "Transit system" can be partially explained by the number of trains/km operated on each line : thus, 2 lines operating 3,26 trains/km have a cost for this chapter equal to 119 MF/km or 22 MUS$/km, 1 line with 2,98 trains/km has a cost for this chapter equal to 114MF/km or 21 MUS$/km, at last 1 line with 1,11 train/km has a cost equal to 93 MF/km or 17 MUS$/km.

The Light Rail lines are designed to supply of around 2500 places/h/dir. with one-car trains, the VAL's lines are designed to supply 9600 places/h/dir. with one unit trains.

The commercial speed of Light Rail is 20 km/h in France while the commercial speed of VAL is 33 km/h, this being principally due to the necessary segregated right of way to operate an Automatic Guided Transit.

Definitively, these above costs show that on average among several lines :

- the equipment linked to the integral automated system control and the rolling stock of an AGT as the VAL has a cost equal to double that of the equipment linked to the Light rail system and its rolling stock cost (113 MF/km or 21 MUS$/km against 58 MF/km or 11 MUS$/km), for the first system the supply is 9600 places/h/dir. and for the second the supply is around 2500 places/h/dir..

- the civil engineering and the appended expenditures have a cost for the VAL's system equal on average to the double that of LRT civil engineering cost (192 MF/km or 36 MUS$/km against 89 MF/km or 17 MUS$/km), the segregated right of way generally obtained by a 75 to 90 % tunnelling construction of a line, the Light Rail is satisfied with a separated right of way on the surface with only 10 % tunnelling construction of the line.

III. 2 Operating costs

From a comparative analysis of operating costs of Lille, Lyon and Marseille metros done by the French Ministry of Transport and data of Urban Community of Lille (CUDL), the operation costs of Lille's metro for the year 1986 (after 2 full years of operation of the first line 13,3 km long with 38 one unit trains), for the year 1988 (61 trains) and for the year 1990 (2 lines of 25,3 km long under operation with 83 trains) the amount of supplied passenger places-km, of annual trips with the corresponding costs are represented in the table below in Francs & US$ (ex. tax).

VAL de LILLE	1986	1988	1990
P.P.K. in millions	454,7	481,09	890,3
Trips in millions	27,07	29,43	44,21
Operating Costs	87,76 MF 12,66 M US$	98 MF 16,44 M US$	135 MF 25 M US $
P.P.K. cost	0,1930 F 2,78 US cents	0,2037 F 3,42 US cents	0,1516 F 2,8 US cents
Trip cost	3,24 F 0,47 US $	3,32 F 0,56 US $	3,05 F 0,57 US $

P.P.K : Passenger Place-km.
O.C. : Operating Cost.
Average value of US$: on 1986 1US $ = 6,93 FF
1988 1 US$ = 5,96 FF
1990 1 US$ = 5,45 FF

The operating costs of Nantes LRT are gathered for the years 1987 (1 line 10,6 km long with 20 trains) and 1990 (after 2 full years of operation of the first line 12,6 km long with 28 trains) the amount of supplied passenger places-km, the amount of trips carried out by year with corresponding costs are represented in the table below in Francs & US $ (ex. tax) :

NANTES LRT	1987	1990
P.P.K. in millions	151	210
Trips in millions	13,07	13,26
Operating Costs	22,918 MF 3,81M US $	33,6 MF 6,16 M US $
P.P.K. cost	0,1517 F 2,5 US cents	0,1599 F 2,9 US cents
Trip cost	1,75 F 0,29 US $	2,53 F 0,46 US $

Average value of US$: on 1987 1US $ = 6,01 FF
1990 1 US$ = 5,45 FF

Nantes networks.

The 1986 & 1987 costs can be compared by their value, the inflation between these 2 years is near zero.

The necessary staff to operate VAL in Lille and LRT of Nantes are represented below :

	LILLE		NANTES	
employes	1986	1992	1987	1992
drivers	0	0	42,2	59,5
operation	77	100	4	11
maintenance	50	70	30,5	58
technicians	41	70	0	0
clerks	22	20,8	9,6	9,5
total	190	260,8	86,3	138
km . trains	2 953 000	5 763 000	899 000	1 233 000
km.trs./empl.	15 542	22 097	10 417	8 935

On Lille's network, the productivity per employee is 15542 km.trains in 1986 and increased to 22097 km.trains in 1992 that is to say an increase of 42%. The second line's commercial operation began on April 1989 with 38,6 employees more who supplied 1 976 000 km trains during 7 months.

On Nantes LRT network the productivity per employee is 10417 trains.km in 1987 and decreased to 8935 trains.km in 1992 that is to say a decrease of 16,5%. In the case of Nantes, the second line's commercial operation began (5,4 km long) on september 1992 with 28,4 employees more who supplied 161000 trains.km during three months.

One of the argument to make the choice of a separated right of way urban transport system is the better mastery of operating cost that this system makes possible. From the data given each year by the French Ministry of Transport in a "statistical book on Urban Public Transport" we can write the table below concerning Lille and

For each of the 2 networks of urban transport (buses and metro), expenditures and operation's fare income have evolved as the following manner in current MF :

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
LILLE Expends in MF	217	258	388	433	449	464	472	479	516	535	552
Fare income in MF	109	138	184	217	236	255	264	278	320	349	361
Fare income/ Expends	0,50	0,53	0,47	0,50	0,53	0,55	0,56	0,58	0,62	0,65	0,65
NANTES Expends in MF	141	156	204	228	233	239	237	265	270	281	299
Fare income in MF	74	81	89	102	111	121	120	117	117	133	141
Fare income/ Expends	0,52	0,52	0,44	0,45	0,48	0,51	0,51	0,44	0,43	0,47	0,47

These ratios correspond to the data of the whole networks (buses & metro) and are lower than fare income/expends ratios of the metros alone.

Thus, in Nantes the fare income/expends ratio of the Light Rail line in 1987 is of 115% when the ratio of the whole line is 51%.

In the same way in Lille, the fare income/expends ratio of the VAL's first line is111% on 1986 when the whole network ratio is 53%.

The progression of this ratio has some consequences on the operation's subsidies evolution, so we can note in the table below how evolve the subsidies given to Lille and Nantes Public transport networks. This balance - sheet is however incomplete because the expenditures taken on account do not include investment costs which are paid by local Organising Authorities.

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
LILLE Subsidy	121	161	190	208	210	208	198	178	178	173	181
Trips in millions	51	59	69	75	75	78	81	90	95	95	99
NANTES Subsidy	89	104	104	109	112	111	134	131	136	142	140
Trips in millions	49	50	51	58	65	67	64	71	68	78	78

In the case of Lille, the amount of operation's subsidy goes on to increase after the opening of the metro first line, the number of trips increases from 51 to 78 millions between 1982 to 1987 that is to say a progression of 53% while the subsidy increases from 121 MF to 208 MF that is to say 72%. With the opening of the second metro's line the number of trips increases again from 78 to 99 millions between 1987 to 1992 that is to say 27% of progression while the subsidy begins to decrease from 208 MF to 181 MF that is to say 15%. As a whole, during 11 years the ridership has increased of 94% while the subsidy has increased of 50%.

In the case of Nantes, the amount of the operation subsidy goes on to increase between1982 to 1992 that is to say 57% while ridership increases of 59%.

What's happened since 1986 on the Nantes and Lille's networks ?

- In Nantes there was the opening of 2 km (double tracks) on the first Light Rail line on 1989 with 8 supplementary one unit trains for the operation then on septembrer 1992 there was the opening of the second line (south phase) 5,4 km long and 5 supplementary trains. The ridership which was of 64,88 millions trips on 1986, became 70,53 millions trips on 1989 and 77,84 milllions trips on 1992 that is to say a progression of 19,9% during 6 years. Nevertheless the rate of coverage of the cost of the service for the whole network (buses and light rail) lower a little from 51% on 1987 to 47% on 1992 in spite of the good results of the light rail line (coverage rate of 115% on 1987).

- In Lille, there was the opening of the line1bis (first phase of the second line) 12 km long on april 1989, with 10 more one unit trains in 1987 and 35 supplementary trains in 1989. The ridership of the network which is 75,48 millions trips in 1986, became 89,73 millions trips in 1989 and 99,25 millions trips in 1992 that is to say a progression of 31,5% during 6 years. In the same time, the operating cost coverage rate which is 53% on 1986 for the whole network became 58% on 1989 and 62% on 1992.

Summing up, we can say :

- In Lille, the "metro influence" with the opening of 2 lines 25,3 km long stimulates the ridership which was low 51 millions trips with the urban transport perimeter of 1 079493 inhabitants, on 1992 this ridership was doubled; the ratio trips/capita is 91,9 in 1992 for an average ratio 121,5 in this range of cities.

- In Nantes, the "metro influence" with the opening of 2 lines 17,4 km long (the opening of the second line 5,4 km long does not appear in our data because it opened only on september 1992) is less significant, the network's ridership before the opening of light rail line was yet 51 millions trips with a urban transport perimeter of 505281 inhabitants, on 1992 this ridership was 78 millions trips; the ratio trips/capita is 154 in 1992 for an average ratio 121,5 in this range of cities.

We sum up the main results of the Lille and Nantes networks between 1980 and 1992 in the table below:

	LILLE				NANTES			
	1980	1986	1992	%	1980	1986	1992	%
Operating cost of network in MF	188	471	558	196	116	239	299	158
Subsidy in MF	97	210	181	87	62	112	140	125
Number of buses	365	402	395	8	334	365	412	23
Ridership in millions trips	51	75	99	94	44	65	78	77
Trips / capita	48	72	92	92	103	140	154	50
Fare income / Expends	48,6	53	65	34	42	48	47	12

IV Main technical evolutions of LRT and AGT systems

IV. 1 Light Rail's evolutions

Evolution of the rolling stock

Light Rail Transit vehicles must be attractive, hence modern. The trend of the last years is an increase in transport supply and productivity : vehicles are 20 to 40 m long and 2,20 to 2,65 m broad with possibility of forming unit trains (one line in Guadalajara is designed to operate 5 unit trains 150 m long); the unit capacity of these vehicles is between 200 and 300 passengers.

The use of choppers with traction engines allows a progressive traction control offering rolling comfort and a better use of adherence as well as consumption savings during starting and at reduced speeds; it is possible to recover electric energy in braking if the electric installation is well adapted.

Asynchronous motors fed by inverters appear progressively, offering a reduction of the expenses for maintenance of the motor , a reduction of weight and volume of the motor, an increasing of maximum rotation speed and a reduction of equipment.

Acceleration performances are required for increasing the commercial speeds, so we assist to an increasing propulsion power : nowadays the power-to-weight ratio is between 12 and 14 kw/tonne.

The tendency of many networks in Europe is to adopt a low floor for their new rolling stock. These networks adopt vehicles with low floors in order to facilitate their access especially by handicapped persons, in order to improve exchange times at stations and facilitate the insertion of platforms into urban space ; thus, in 1984, the Geneva network adopted an articulated vehicle (Düwag & Vevey) whose floor is situated at 48 cm of the rolling level on a length of 12,5 m in front of the accesses, but there remains a step set without access of wheelchairs. The Grenoble network put into service vehicles with extra-low floors, derived from the French standard tramway (GEC-Alsthom) whose floor is situated at 34,5 cm above the rolling level on a continuous length of 17,85 m in front of the accesses. Since that period many networks adopt low - floor LRVs which can be classified in three types:

- the intermediate Low-Floor unit added to existing rolling stock, approximately 150 of this design are in use in Amsterdam, Wurzburg, Darmstadt, Freiburg, Basel and Nantes networks,

- the partial Low-Floor between traction bogies, more than 750 LRVs of this design are in use in Grenoble, Paris (St Denis), Rouen, St Etienne Sheffield,etc. networks,

- the 100 percent Low-Floor design, no steps inside, which is under operation in the Lille, Bremen, Frankfurt, Strasbourg, Bruxelles, Bonn, soon in Köln, Munich, Zwickau, Braunschweig, Vienna networks. In all, more than 400 all-low-floor vehicles have been delivered or ordered.

Operating methods and traffic control

In order, on the one hand to ensure traffic safety in the zones with exclusive right of way, and on the other hand to improve regularity of the lines on mixed-traffic space, numerous networks have introduced aids to the operation of the tramway lines. These aids can be classified into three categories :

- *block system of the track* by means of track loops and spacing signalling on the line sections with exclusive right of way, especially in tunnels;

-*priority at junctions with traffic lights.* One obtains considerable improvement of LRT operation, if a great part of the network has separated tracks and if stoppage times are suppressed at level junctions with general traffic : in fact, the major part of time losses due to causes outside operation come from signalling with traffic lights. In certain cities, this can represent 10-20% of turnround times.

- *systems of supervision and areawide traffic control : setting up of a LRV fleet management and Automatic Vehicle Location (AVL) system..*

Such systems are particularly useful for the integration of services ensured by buses, tramways and LRT vehicles in a city, for they can supervise the whole operation, detect incidents, allow the obedience of timetables so that transfers can be smoothly ensured. The computer locates the vehicles and compares the theoritical situations with the real situations on the lines : this is the on-line follow-up of operation. The analysis of collected information allows the recording of incidents and statistics, allowing to improve operation : this is the off-line follow-up of operation.

The potential of Light Rail Transit

A study made among 10 networks around the world, by the Transport Research Laboratory (TRL) and INRETS in 1993 on the theme of the performance and potential of light rail transit in developing cities shows that the observed maximum peak hourly flows were found in three networks with a high percentage of separated right of way in Tunis (9330 pas./h/dir.), Alexandria (El Ramel 13414 pas./h/dir.) and Manila (a 100% segregated right of way, on viaduct : 18892 pas/h/dir.), the other 7 networks have an average flow of 4500 pas./h/dir at peak hours.

The passenger throughput on each system broadly reflects the train flows; on the street-running systems, maximum flows range from just over 3000 pas./h/dir. to just over 6000 pas./h/dir. The LRT systems were carrying maximum passengers flows of between 3000 - 19000 pas./h/dir., the upper figure being achieved on Manila's fully segregated system.

So it is full segregation, an advanced signalling system providing theoritical minimum headways of 85 seconds in Manila, 105 seconds in Mexico (line A) , 150 seconds in Guadalajara , and a number of vehicle well adapted that can supply a high capacity :

- in Manila the designed capacity with a 85 seconds headway is 52000 pas/h/dir. with 3 units trains (vehicle capacity of 415 pas. (8 pas/m^2)), nowadays there are only 2 units trains with an headway of 167 seconds that is to say 18000 pas./h/dir.
- in Guadalajara the designed capacity of the line 2, fully segregated in tunnel, with a 150 seconds headway is 46000 pas/h/dir.with 5 units trains (vehicle capacity of 388 pas.(8 pas/m^2)), nowadays there are only 3 units trains with an headway of 300 seconds that is to say 14000 pas./h/dir.
- in Mexico the designed capacity of the line A, fully segregated, with a 105 seconds headway (with SACEM ATP and ATO) is 61700 pas./h/dir. with 9 units trains (vehicle capacity of 200 pas.), nowadays there are only 6 units trains with an headway of 288 seconds that is to say 15000 pas./h/dir.

These three systems are fully segregated (Manila line on a viaduct, Guadalajara line in a tunnel, Mexico line on surface) with long trains and short headways, they need advanced signalling system for operation and safety, can we call them Light Rail Transit systems ? We think that when they could operate at their designed capacity , they will be merely conventional metros.

IV. 2 Automatic Guided Transit's evolutions

The first lines under construction and operation of the VAL system (Lille two lines, Toulouse two line, Orly one line) are characterised by the following features :

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

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

Use of microprocessors for safety functions

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 the safety functions, RATP has promoted the development of an architecture based on a single microprocessor protected by data coding, called "vital coded monoprocessor".

This new architecture is now a standard for safety realisations in mass transit systems 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 and Line 8 (Urban metro) and Line A (LRT) of Mexico network.

Development of a moving block (ATP) system

Lyons' Authorities decided to adopt a moving block Automatic Train Protection (ATP) for the 4th line of their metro network in order to obtain a better flexibility of operation : a study conducted in Lyon 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 facility could lead to significant savings, in order of 3 MF/year (0,5M US$/year val.87), in electric energy and in maintenance.

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. In Lyon, the Authority and the metro operator choosed a conventional method based on a double barrier of infrared beams, regularly spaced with 15 cm intervals, layed down above the tracks.

Automatisation of D-line in Lyons'metro

An evaluation made for the automatic operation's project on the line D by the SEMALY in view of comparing a system with automatic driving with one driver and a system with entirely automatic driving leads to the following global balance sheet :

- supplementary investments due to entirely automatic operation : about 200 MF (ex tax val.jan.1985) or (with 1US$ = 8,98 FF val.85) 22,3 M US$. The decision of adopting entirely automatic driving was taken late, when the construction of the line was already undertaken, which led to important supplementary costs.

- savings of operating costs excluding depreciation : 12 MF/year (jan 87) or 2 MUS $ /year val.87.(with 1 US$ = 6,01 FF val.87). This saving is anticipated compared to traditional operation with driver (namely some 20% of the traditional line operating cost).

The decision of automatising D-line was not only adopted for the savings on operating costs but, above all, because a fully automatic driving system gives :

- an operating flexibility with possibility of very rapid modification to and adaptation of the operating program and the planned use of trains with variable make-up (2 or 4 cars) so that supply can better meet demand,

- a staff management facilities to the operator,

- allows to give to the users the service quality they need.

Comparison between the capacities of the MAGGALY and the VAL 206 systems:

- at a normal load a vehicle MAGGALY 2,90 m wide, carries 132 passengers (4 pas./m^2) and 170 passengers (6 pas./m^2) at an exceptional load; at the peak hour, with a minimum headway of 90 seconds the supplied capacity with 2 car-trains is 10560 pas./h/dir. and increases until 21120 pas./h/dir. with 4 car-trains at a normal load and 27200 pas./h/dir. These capacities can be compared to the 26160 pas./h/dir. capacity of a VAL 206 2 car-trains at an exceptional load and 31680 pas./h/dir. capacity of 4 car-trains VAL 256 : the difference is in the minimum headway which is 60 seconds for the VAL and 90 seconds for the MAGGALY.

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 vehicles 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,

. a new VAL vehicle called VAL 208 : the main evolution of this vehicle is the"wheel-motors", it means one motor for each weel of the vehicle instead of 2 DC motors in each vehicle, with a traction chopper for each of them; the motor is of the synchronous type with permanent magnets, with an IGBT DC/AC converter; so each train set has 8 wheel-motors.

As for the suspension, there are always four suspension pneumatic tired wheels per vehicle, with the new VAL 208, instead of the rotation of the whole axle, each suspension wheel pivots.

IV . 3 Large gauge Automatic Guided Transit Systems

In the chapter above, we make the description of the new Lyons' MAGGALY system which can supply a capacity until 21120 pas./h/dir. at a normal load with vehicle of 2,90 m wide. The networks of Taipeh and Paris have also adopted large gauge automatic guided transit systems:

- the city of Taipeh has adopted for one line, the Mucha line 11,5 km long running on a viaduct, the VAL 256 (2,56 m wide) : at a normal load, each vehicle carries 92 passengers and 132 passengers at an exceptional load; at the peak hour, with a minimum headway of 60 seconds the supplied capacity with 4 car-trains at a normal load is 22080 pas./h/dir. and 31680 pas/h/dir. at an exceptional load. The cost of aerial infrastructure is less sensible to the width of vehicles than underground infrastructures. 102 vehicles will carry on this line a yearly ridership of 35 millions passengers.

- in Paris, RATP, has decided to create a new fully-automated metro line called METEOR (Metro Est Ouest Rapide). The purpose of Meteor is to relieve traffic on the RER A line (Regional metro) and provide better service to Paris' inner suburbs : the objective of this line 19,6 km long with 20 stations (with platform doors) is to carry 40000 pas./h/dir. The 8 car-trains (120 m long, 2,50 m wide) of a total capacity of 952 passengers at a normal load will run with an interval of 85 seconds at a commercial speed of 40 km/h. The first phase will be 7,2 km long with 7 stations, the operation will be made with 6 units trains 90 m long of a capacity of 714 passengers that is to say at the peak hour 30000 pas./h/dir.

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. The command and control proposed system is closely derived from the MAGGALY system : the compatibility with manually operated trains is obtained by a synthesis between a data base design, a fixed block signaling and a performing operation, due to a small block length, this new concept is called "virtual fixed block".

So, if at the beginning the consequence of application of fully automated driverless operation was the reduction of vehicle unit capacity, the productivity of operation being not cancelled by the increased number of automatic cars under operation, the trend nowadays is to applied fully automation to new high capacity metros or existing metros whatever the needed capacity !

V Conclusion

After an important decline in the fifties, Tramways have recovered with Light Rail Transit a certain dynamism taking expression :

- in the creation of new networks, 300 urban tramway networks in the world in 1975, there will be over 400 networks by the year 2000; the renewal of interest for this type of transport is particularly clear in the United States and United Kingdom;
- in the improvement of existing networks, by increasing the exclusive and separated right of way, allowing to obtain very satisfying commercial speed on some lines ;
- in the improvement of rolling stock with extra low-floor light rail vehicules which will be more than 1000 units in operation by the end of 1994 ;

The main reason of this dynamism is that these systems can be operated at grade on surface, they can be developed in stages from a streetcar system that shares its right of way with other traffic to a transportation system which operates substantially on exclusive right of way.

Light Rail Transit is particularly well adapted to a range of cities and conurbations with populations between 200,000 and 600-700,000 inhabitants, in which the construction of underground networks is hardly imaginable because of the necessary investments.

AGT systems have a service quality, a flexibility, a regularity of metronome, a safety that the LRT can reach in the same way with difficulty ; the main reason is because AGT uses a fully automated driverless operation but it requires fully exclusive right of way and stations, and with higher car and system costs, total AGT construction cost is invariably higher than LRT construction cost.

We saw in the chapter above "Comparison of 2 systems" that :

- From the investment point of view

. on average, the equipment linked to the integral automated system control and the rolling stock of VAL has a cost equal to double that of the equipment linked to LRT system and its rolling stock cost, for the first system the supply is 9600 pas./h/dir. and for the second the supply is around 2500 pas./h/dir. As for the civil engineering and the appended expenditures, they have a cost for the VAL's system equal on average to the double that of LRT civil engineering cost, the exclusive right of way generally obtained by a 75 to 90% tunnelling construction of a line, the Light Rail is satisfied with a separated right of way on the surface with only 10% tunnelling construction of their line.

- From the operating cost point of view

. in Lille, the "metro influence" with the opening of 2 lines 25,3 km long stimulated the ridership, the passenger Place-km cost which was 0,2037 F at the opening of the second line decreased to 0,1516 F after two years of the 2 lines operating. The productivity per employee was 15542 km.trains in 1986, it became 22097 km.trains in 1992.

. in Nantes, the "metro influence" is less significant, the productivity per employee was 10417 trains.km in 1987, it became 8935 trains.km in 1992, the passenger Place-km cost which was 0,1517 F in 1987 increased slowly to 0,1599 F in 1990.

We think that to increase the productivity of investment costs, the VAL system needs to operate in a high density area ,not necessarily large city, and with important vehicle fleets the operating costs will decrease, the productivity per employee going on increasing with the opening of new lines of the network. With a large number of cars to operate the AGT operating costs decrease in relation with the LRT operating costs for a same supplied capacity.

When a city has a lack of land, generally in the centre, the future transit system needs to be up-graded (in underground or on viaduct), the construction cost of the system increases ; then there is a choice to do between an LRT or an AGT system because the exclusive right of way is naturally necessary. An automatic guided transit with its flexibility, service quality, safety could be implemented with an acceptable overcost decreasing when the needed capacity grows.

At last, we think there is a need of the two systems for the cities, larges or not :

- a high density city without land to give to surface public transport could choose an AGT if the ridership to carry is sufficient, the service quality is then high and the "image of metro" attracts the users of private cars,
- a middle size city which makes the choice to prohibit some roads to the private cars, could then get separated right of way for a Light Rail and decides to implement it : Light Rail schemes of the 1980s have shown that street operation with predomently reserved running is both feasible and actually contributes to the humanising of the city.

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