FINANCIAL ASSESSMENT OF FULLY AUTOMATIC URBAN MASS TRANSIT SYSTEMS

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abstract: As a financial assessment of completely automation in the field of urban public transportation, this paper aims to evaluate the cost/benefit of a French fully automatic transit system (the VAL of Lille), in comparison with one-man operated conventional metro lines such as that of the Paris Metro. Three types of comparisons are proposed and they are examined through civil work/system investments, operating/maintenance costs, and costs due to the additional testing/integration period. According to the study, the major financial effects of complete automation are the savings on operating employees and on civil work investments. The financial consequences are more favourable to fully automatic control for lines with shorter trains, with a higher service frequency, which require shorter stations, a larger fleet of vehicles and more drivers.

1. INTRODUCTION

Numerous urban mass transit systems with fully automatic operation have been put into service during the last thirsty years around the world, and most of them are running in a satisfactory way.

In fact, the fully automatic transit system is initially constructed for specific links in special areas, for example, airports, shopping centers, exhibition parks, leisure parks, campuses, etc.. However, at the beginning of 1980s, it made a noticeable entrance into urban public transportation with the opening of the Japanese New Transit systems in Kobe and Osaka, and the French VAL system in Lille.

Now, the fully automatic transit systems have won a good reputation with a lot of solid operating experiences and stand as a variant to be seriously taken into consideration for any new urban transport project. Among the main motivations for adopting such a mode of operation, we can mention:

- the high level of safety and high reliability which may be attained;

- the improvement in service quality by offering the users a high train frequency;

- its flexibility in operation;

- the cost to be paid for these improvements dose not appear excessive, especially considering the saving on operating employees, and on civil works if the “mini-metros” or “medium-sized vehicles” are chose.

This last point, concerning the costs of driverless automated systems with small vehicles, is nowadays a very important issue for all urban transport constructors and operators. In order to evaluate the investment, the operating and maintenance cost-efficiency of complete automation when it is introduced to the field of urban public transportation, three types of comparison are undertaken in this study:

- on two lines with different operating modes but possessing the same geometric characteristics, the same rolling stock and the same service frequency;

- on a fully automatic line with short trains, and a one-man operated conventional metro line with long trains, where in both cases, the lines are equipped the same type of rolling stock;

- on a fully automatic line with short trains and small vehicles, and a one-man operated conventional metro line with long trains and large vehicles.

2. FIRST COMPARISON: two identical lines with the same rolling stock and service frequency, one with manual driving and another with fully automatic control

For a financial assessment of fully automatic urban mass transit system, one of the least controversial ways is to compare, on a well-defined given line, two different modes of operation - one with manual driving and another with fully automatic control. And in this background, we can examine the different costs to which these two different operation modes can lead.

In this study, we choose as reference a French urban mass rapid transit line comparable to line 1 of the Lille’s VAL, whose main characteristics are summarized below.

Table 1: The main characteristics of the line 1 of Lille's VAL

Date of commercial service opening	May 16, 1983
Length	13.3 km
Number of stations	18
Rolling stock in operation	46 married pairs, 1 married pair = 2 cars
Commercial speed	34 km/hr
Minimum headway	60 seconds with 25 seconds dwell time in station
Maximum capacity (normal load: 4 passengers/m^2)	9 240 passengers/hour/direction
Duration of the round trip	48 minutes
Total train-kilometers	4 888 000 / year in 1994

The problem raised consists in comparing the financial items such as system investments, cost of additional period for system testing and integration, operating and maintenance costs, of the two following basic operating modes:

- mode 1: one-man operated with a conventional automatic train operation (ATO) system of the Paris Metro type, PA 135 kHz, which is supplied by the French company MATRA Transport. We take this mode as a reference because it is wide-spread at present, its design concept is close to that of the VAL system - another important product of MATRA Transport, and it allows performances approximately identical with those in mode 2 in the quality of service, especially in service frequency, regularity and safety;

- mode 2: the VAL type fully automated guideway transit system.

The assumptions of this comparison are the following:

- the general characteristics of the line remain the same in the two cases: the same infrastructure, the same track and the same rolling stock but with different fixed and on-board ATC equipment;

- the transport demand dose not change, neither dose the supplied transport capacity. The train frequencies, the amplitude of service periods - representing about 20 hours - as well as the numbers of vehicle ·km offered are the same in two cases. This assumption is acceptable as far as in both cases the line is operated automatically most of time, and in mode 1 a longer period of peak hour service and a sufficient number of drivers and staff in terminals have been provided in order to meet supply conditions;

- the operating policies on the subjects of toll, ticket control, and fraud prevention are the same in the comparison;

- finally, in these two cases of study, the same policies of maintenance, and the identical level of subcontracting are applied.

Consequently, the principal items in the financial assessment are the following:

2-1. Costs of the control system

(1) At the level of the on-board equipment

Firstly, in the on-board ATC rack equipment, there are 5 important racks in mode 2: DCA (automatic piloting device) rack, safety rack, TM/TC (telemetry and telecontrol) rack, feeding rack and BST (traction safety block) rack. On the other hand, mode 1 is only equipped with the three basic racks: DCA rack, feeding rack and safety rack. It is to be noted that telemetry and telecontrol equipment is much more developed in mode 2 than in mode 1.

Besides, in mode 2 all the on-board ATC equipment is made redundant in order to ensure that the train has an availability that, in mode 1, can be safeguarded by the presence of a driver.

Secondly, the equipment of the driving cab of mode 1, which is generally designed for the service of only one on-board driver, is of course heavier than that of the assistant manual driving desk of mode 2.

Thirdly, in order to ensure the automatic operation, in mode 2, the train are equipped with complex antennas and sensors, such as 2 reception antennas, 2 anti-collision emission antennas, 1 telemetry emission antenna, 1 phonic emission antenna, 1 LSV (station/vehicle connection) antenna, 1 beacon detector, 2 phonic wheels, 2 tachymetric generators, 1 accelerometer and 8 tire deflation detectors. While in mode 1, a conventional metro with the PA 135 kHz control system, this equipment is in general limited to 2 reception antennas, 2 phonic emission/reception antennas, 1 beacon detector, 1 phonic wheel, 1 accelerometer and 8 tire deflation detectors.

(2) At the level of fixed equipment

Firstly, the absence of drivers implies more telemetry and telecontrol information exchanges between the trains, the ground and the control center. Mode 2 therefore requires better performing links between the trains and the ground, and between the fixed equipment and the control center, as well as a higher processing capacity of the control center.

On the other hand, a manual mode must be equipped with heavier wayside visual signals than an entirely automatic mode. In the latter, commuting into manual driving is considered as a very rare event during which a certain degradation of service quality can be tolerated, so the visual signals are simplified.

Secondly, in the station of a fully automatic line, a protection must be provided against the risks of passengers falling onto the tracks or being dragged away jammed between the train doors. In all of the lines of the VAL system, except for the Jacksonville Skyway Express, this protection is ensure by platform screen doors. With this kind of protection, the necessity of accurate stopping of the trains (+ or - 30 cm) in front of the platform doors requires a special electronic device (EAS) in stations, in order to ensure the management of the stopping sequence and door opening/closing maneuver.

Thirdly, the absence of drivers also requires the installation of ATC equipment in the maneuver and garage zones. This is not necessary in mode 1 because there is always a driver on-board.

Finally, the fixed ATC equipment is, just like the on-board on, redundant in mode 2 for ensuring a good availability of the line.

2-2. Costs of rolling stock

In the first comparison, the two modes are equipped with the same type of rolling stock. But it must be noted that the presence of a driving cab for each end of the train in mode 1 reduces slightly the space offered to users, even if we take into account the volume saving due to the reduction of on-board ATC equipment. At least 1 m2 at each end, or 4.8 % of the useful space in a VAL 206 married pair train, is lost in this way. It means that we must add some trains to the line of mode 1, in order arrive at the same transport supply.

2-3. Costs in studies and testing

When we evaluate the differences on the material investment between the modes 1 and 2, it would be proper to add the supplementary costs in studies and testing to mode 2. In fact, putting into service a fully automatic line requires a considerable number of integration tests and safety studies which are absolutely not comparable with the requirements of a conventional metro line.

2-4. Costs due to the necessary time of testing and integration

Moreover, we should take into consideration the financial effect of the necessary time of testing and integration on an entirely automatic line. Generally, in comparison with a conventional metro line, a VAL type automatic line needs an extra period of about 3 ~ 6 months for its dynamic testing and system integration. There are certainly capital losses due to this additional period. These losses will obviously vary with the variations of the length of period and of discount rate.

2-5. Operating costs

2-5-1. Operating staff

Between mode 1 and mode 2, the differences in the field of operating staff essentially concern:

(1) Control center staff: The absence of drivers implies that much more information must be processed in the control center, especially for the management of terminals and garages, which require on average 1.5 supplementary agents in mode 2 in comparison with mode 1. It translates into a supplementary control center staff of 9 persons for the 6 shifts.

(2) Driving staff:

For an amplitude of service of about 20 hours and for the practical headway (from one train every 1 minute to one train every 6 minutes) on the line 1 of Lille's VAL, there are 515 round trips for daily commercial service. It needs 44 trains in line for the peak hours and 1 reserved train in each terminal. (see table 2)

Table 2: Standard service schedule of the line 1 of Lille's VAL

515 departures from Quatre Cantons			515 departures from C.H.R. B - Calmette		
Schedule	Departures	Interval	Schedule	Departures	Interval
05:12:00 ~ 05:24:00	2	6:00	05:12:00 ~ 05 :24:00	2	6:00
05:24:00 ~ 06:12:00	12	4:00	05:24:00 ~ 06:12: 00	12	4:00
06:12:00 ~ 06:52:00	20	2:00	06:12:00 ~ 06:52:00	20	2:00
06:52:00 ~ 07:04:00	9	1:20	06:52:00 ~ 07:04:00	9	1:20
07:04:00 ~ 07:36:00	32	1:00	07:04:00 ~ 07:36:00	32	1:00
07:36:00 ~ 08:48:00	54	1:20	07:36:00 ~ 08:48:00	54	1:20
08:48:00 ~ 09:36:00	24	2:00	08:48:00 ~ 09:36:00	24	2:00
09:36:00 ~ 11:24:00	36	3:00	09:36:00 ~ 11:24:00	36	3:00
11:24:00 ~ 12:46:00	48	1:43	11:24:00 ~ 12:46:00	48	1:43
12:46:00 ~ 13:36:00	25	2:00	12:46:00 ~ 13:36:00	25	2:00
13:36:00 ~ 15:00:00	28	3:00	13:36:00 ~ 15:00:00	28	3:00
15:00:00 ~ 16:10:00	35	2:00	15:00:00 ~ 16:10:00	35	2:00
16:10:00 ~ 18:10:00	100	1:12	16:10:00 ~ 18:10:00	100	1:12
18:10:00 ~ 19:24:00	37	2:00	18:10:00 ~ 19:24:00	37	2:00
19:24:00 ~ 20:12:00	12	4:00	19:24:00 ~ 20:12:00	12	4:00
20:12:00 ~ 24:12:00	41	6:00	20:12:00 ~ 24:12:00	41	6:00

For the same service output, the number of necessary trains in line for peak hours that the mode 1 needs is 48. Thus, the duration of the peak hours (one train per minute) of mode 1 is 36 minutes.

Considering the general working conditions of metro drivers in France, we come to 156 drivers for the mode 1, in which we should add 6.7 % of trains dispatchers, that is to say 10 persons.

(3) Intervention staff: The impact of automatic control on the needs for in-line and in-station intervention staff is not easy to appreciate. On one hand, as the existing equipment volume is heavier in mode 2, the equipment failure is likely to be more frequent. On the other hand, in this case, redundancies are provides almost systematically to ensure reliability. After all, with the actual operating experience of the line 1 in Lille and with the supposition that a conventional line always has a driver in the train needing 2 intervention agents for the line, we can estimate that there are 12 supplementary persons in mode 2 for the intervention.

(4) Staff in terminals for the train reversal aid: As far as train changing/shunting in terminal is concerned, in mode 1, there are two important needs:

- headway > 100 seconds, for departures and maneuvers: 17 persons;

- headway ≤ 100 seconds, during peak hours, for the train reversal aid: 7 supplementary persons.

(5) Maintenance staff: There is no significant difference concerning maintenance staff between mode 1 and mode 2, because the operating organization is generally in charge of the ATC equipment first level and second level maintenance operation, meaning that they change defective racks and defective cards for new ones. The third level of maintenance (card repairs) is subcontracted to the supplier. It is obvious that first level and second level of maintenance are simple operations. There is thus no reason to say that the fully automatic line creates a need for more maintenance staff.

But in accordance with the actual experience with the VAL type fully automatic line, a platform screen door needs 3 hours 30 minutes of maintenance per year. In this study, this kind of maintenance demands 756 working hours per year, as well as 1 supplementary person maximum in mode 2.

(6) direction staff: The direction staff is generally 2 % of total personnel, there will de 2 supplementary managers and 2 supplementary clerks added in mode 1.

2-5-2. Maintenance costs other than staff costs

The maintenance of metro line concerning the first comparison consists three principal items: rolling stock, station and fixed equipment maintenance.

(1) Rolling stock maintenance: This kind of maintenance is concerned with 4 parts: car body, traction/braking equipment, on board ATC equipment and other equipment. Most of rolling stock maintenance costs in mode 1 are higher than those in mode 2, except for the maintenance cost of on-board ATC equipment because the former is equipped with 4 more trains. We suppose that all of the maintenance costs depends on the volume of equipment. The total supplementary cost in mode 2 in this item is therefore about 0.93 million French francs per year.

(2) Station maintenance: The only difference between mode 1 and mode 2 in this item is the cost of the platform screen door maintenance. It is estimated at about 30,000 French francs per station per year. In this study, the supplementary cost of this operation in mode 2 is 0.54 million French francs per year.

(3) Fixed equipment maintenance: In this item, the variation costs are the costs of fixed ATC equipment maintenance (including control center, wayside signals and cables). We suppose also that these costs are dependent on the volume of equipment. In the case of line 1 of Lille's VAL, the costs are estimated at 9.3 million French francs per year. The supplementary costs in mode 2 about this item are therefore 3.1 million French francs per year.

2-6. Global Financial assessment

At the end of first comparison, we arrive at the following comparative table (Table 3) which shows the main financial differences between the two operating modes on a given line.

In general, most of financial assessments concerning this type of equipment are made over a period of 20 years corresponding approximately to their average lifetime. The financial consequence of the fully automatic system can thus be calculated by the following formula:

$\Delta F = \Delta I + \Delta P + \Delta E\left(\frac{1-\beta^{20}}{1-\beta}\right)$, where ΔF: financial consequence updated over 20 years; ΔI: difference on system investment; ΔP: supplementary cost due to additional testing and integration period; ΔE: difference on annual expenses; $\beta = \frac{1}{1+\alpha}$; α: discount rate.

In order to draw up such an assessment, we should fix a discount rate applicable to yearly expenses for these 20 years. As the official discount rate used today in economic evaluation in Paris Transport Authority (RATP) is 8%, we apply here three discount rates: 5, 8 and 10% to the limit values figuring in the table 3. The table 4 shows the different results with these different discount rates and with or without the cost of additional testing and integration period.

According to results of the table 4, the financial consequences of completely automation in the field of urban public transportation are clearly positive, with any discount rate chosen, even if we take into account the cost of additional testing and integration period which is necessary for fully automated guideway transit systems. It means that, on a cost/benefit basis and on the line 1 of Lille's VAL, the choice of a fully automatic urban mass transit system is undoubtedly the best.

Table 3: Main financial differences between mode 1 and mode 2

Items	Supplementary costs in million French francs of January 1995	
	Mode 1	Mode 2
System investments		
1. Rolling stock		
1-1. Supplementary cost due to capacity loss connected with the driving cab (4 supplementary trains)	58.7	
1-2. Supplementary cost of on board ATC equipment		15.2
2. Supplementary cost of fixed equipment		
2-1. Low voltage network		15.0
2-2. Wayside ATC equipment		55.0
2-3. Garage and workshop ATC equipment		50.0
2-4. Platform screen doors (18 stations)		30.0
2-5. Control center		20.0
3. Supplementary cost of studies and tests		40.0
Total supplementary investment in mode 2		166.5
Supplementary cost in mode 2 for 4.5 months of additional testing and integration period		95.0
Operating costs		
1. Operating service		
1-1. Control center staff (9 supplementary persons)		2.97
1-2. Driving staff (156 drivers)	39.00	
1-3. Train dispatchers (10 persons)	3.30	
1-4. Intervention staff (12 persons)		3.00
1-5. Train reversal agents (24 persons)	6.00	
1-6. Managers (2 supplementary persons)	0.88	
1-7. Clerks (2 supplementary persons)	0.50	
2. Maintenance		
2-1. Rolling stock	0.93	
2-2. Stations (platform screen doors)		0.54
2-3. Maintenance agent for platform doors (1 person)		0.25
2-4. Fixed equipment		3.10
Total supplementary annual cost in mode 1	40.75	

Table 4: Financial consequence of fully automatic urban mass transit system over 20 years

Discount rate	Benefit updated over 20 years (million French francs in January 1995)	
	a	b
5%	+ 355.1	+ 260.1
8%	+ 265.5	+ 170.5
10%	+ 216.6	+ 121.6

* a: without taking into account the cost of additional testing and integration period;
b: taking into account the cost of additional testing and integration period.

2-7. Variation of financial consequences with the vehicle fleets

For a given line, the financial consequences can vary in a very considerable way with the volume of rolling stock. In fact, we observe that, in a given operating situation, if the number of trains (N) varies:

- in the system investment items, the item 1 "rolling stock" varies proportionally to the number of trains, as 1.06N million French francs. The item 2 does not vary. The item 3 varies very little and its variations can be neglected.

- in the cost of additional testing and integration period, the variation according to the vehicle fleet is small. It is reasonable to neglect it.

- as far as the item of operating service are concerned, for the sub-item "driving staff", "train dispatchers" and "direction staff", the differences can be summed up to 0.96N million French francs per year. On the other hand, the agents in terminals for the train reversal aid are not longer necessary if the minimum interval is more than 100 seconds, it is to say that the number of trains is less than 28.

- in the item "maintenance", only the rolling stock maintenance varies. The variation of supplementary cost in this sub-item in mode 1 equals to 0.015N million French francs per year.

On the above basis, and with a discount rate of 8%, we can distinguish the financial consequence into the three following parts:

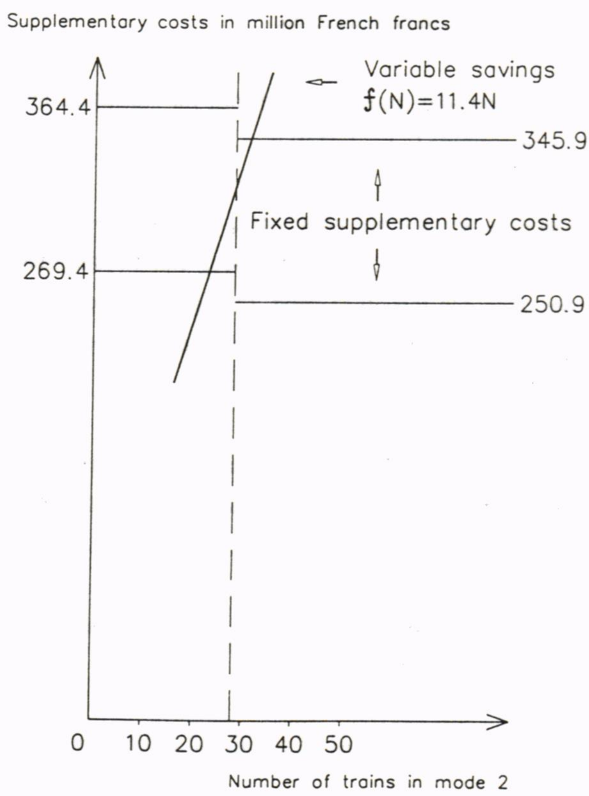
- the fixed part: If we take into account the cost of additional testing and integration period, the total supplementary cost of mode 2 is 409.5 million French francs. If the cost does not be taken into account, it will be 314.5 million French francs.

- the semi-fixed part: If the number of trains ≥ 28, the supplementary cost of staff in terminals in mode 1 is 63.6 million French francs. If the number of trains < 28, the supplementary cost of staff in terminals in mode 1 is 45.1 million French francs.

- the variable part connected with the volume of vehicle fleet: $f(N) = 11.4N$.

The figure 1 shows that, if we take into account the cost of additional testing and integration period, the financial consequences are positive for mode 2 when the line is equipped with 30 trains, that is to say that the minimum headway is less than 95 seconds. And if the cost of additional testing and integration period does not taken into account, this threshold falls to 24 trains corresponding to a minimum interval of 120 seconds.

Figure 1: Variation of the financial consequences of a fully automatic line with the volume of vehicle fleet (over 20 years with a discount rate of 8%)



3. SECOND COMPARISON: a fully automatic line with short trains, and a one-man operated conventional metro line with long trains, where in both cases the lines are equipped with the rolling stock of same width

We know that one of the great difficulties in the field of urban public transportation is to obtain a high system productivity. For the same traffic assignment, we can envisage two possibilities: using long trains and large vehicles to reduce the service frequency entails high productivity of drivers in terms of places-km offered. However, choosing short trains and small vehicles with high frequency is a more attractive possibility for the passengers, and more competitive in urban transport network.

For evaluating the different financial consequences of these two possibilities, we proceed to here a second comparison and in the further paragraph a third comparison, with modes equipped different types of rolling stock.

In second comparison, we compare the mode 2 of first comparison with the mode 1-1: identical to the mode 1 of first comparison, but with a train of 4 cars and a lower service frequency.

The length of stations of mode 1-1 is then 52m, just as the length of trains. But in order to install the necessary equipment, the length of stations of mode 2 must be longer than that of trains (26m). According the study of RATP, there are two basic types of stations with lateral platforms in mode 2: elevated stations (26 m of length) and underground stations (39 m of length).

On the line comparable to the line 1 of Lille's VAL, the main items in the financial assessment are the following:

- Infrastructure investments: With the results of the calculation of RATP, the supplementary cost of infrastructure of mode 1-1 is estimated at 122.1 million French francs.

- Rolling stock investment: The train unit capacity in mode 1-1 is almost double the one of mode 2. For the same traffic and half service frequency, the mode 1-1 must be equipped 2 supplementary trains of 4 cars. On the other hand, there are 52 million French francs of supplementary cost of on board ATC equipment in mode 2.

- Fixed equipment investment, study and testing investment, cost in mode 2 for the 4.5

months of additional testing and integration period: We suppose that the situation is identical to the first comparison.

- Operating staff cost: Considering that the minimum interval of mode 1-1 is about 115 seconds and the maximum one is reduced to 11 minutes 30 seconds, the number of driver is 75. It needs therefore 5 train dispatchers and 2 direction staff. It is noted that the minimum headway in mode 1-1 is more than 100 seconds. Consequently, no train reversal aid agent is required and the number of agents in terminals is 17.

- Supplementary maintenance costs other than staff costs: (1) Rolling stock maintenance: 3.08 million French francs per year in mode 2; (2) Station maintenance: 4.65 million French francs per year in mode 1-1; (3) Fixed equipment maintenance: 3.08 million French francs per year in mode 2.

Different from the first comparison, most of financial assessments concerning infrastructure are made over a long period from 50 to 100 years. We suppose here that the average lifetime of civil works is 60 years. But it is noted that the lifetime of system equipment remains 20 years, so we must renew all of them over these 60 years.

Table 5 was draw up with the above data. The financial consequences over 60 years remain still positive if we does not take into account the cost of additional testing and integration period. If the cost of additional testing and integration period is taken into account, the consequence is negative with the discount rate of 10%. Where the saving on drivers and on civil works can not totally compensate for the supplementary system investments and yearly maintenance costs of mode 2.

Table 5: Financial consequences of the second comparison over 60 years

Discount rate	Benefit updated over 60 years (million French francs in January 1995)	
	a	b
5%	+ 170.5	+ 75.5
8%	+ 107.7	+ 12.7
10%	+ 81.4	- 13.6

* a: without taking into account the cost of additional testing and integration period;
b: taking into account the cost of additional testing and integration period.

As the first comparison, the financial consequences of second comparison vary noticeably with the volume of rolling stock. We observe that, in a given operating situation, if the number of trains (N) varies:

- the investments of infrastructure and of fixed equipment does not vary.

- the supplementary investment "rolling stock" of mode 1-1 varies proportionally to the number of trains, as (26.1 - 0.3N) million French francs.

- in the cost of additional testing and integration period, the variation according to the variation of vehicle fleet can be neglected.

- as far as the operating service are concerned, for the sub-items "driving staff", "train dispatchers" and "direction staff", the differences can be estimated at (0.42N + 0.75) million French francs per year.

- the supplementary annual maintenance costs of mode 1-1 are estimated at (0.277 - 0.073N) million French francs per year.

On these basis, and with the discount rate of 8%, we can distinguish the financial consequence into the two following parts:

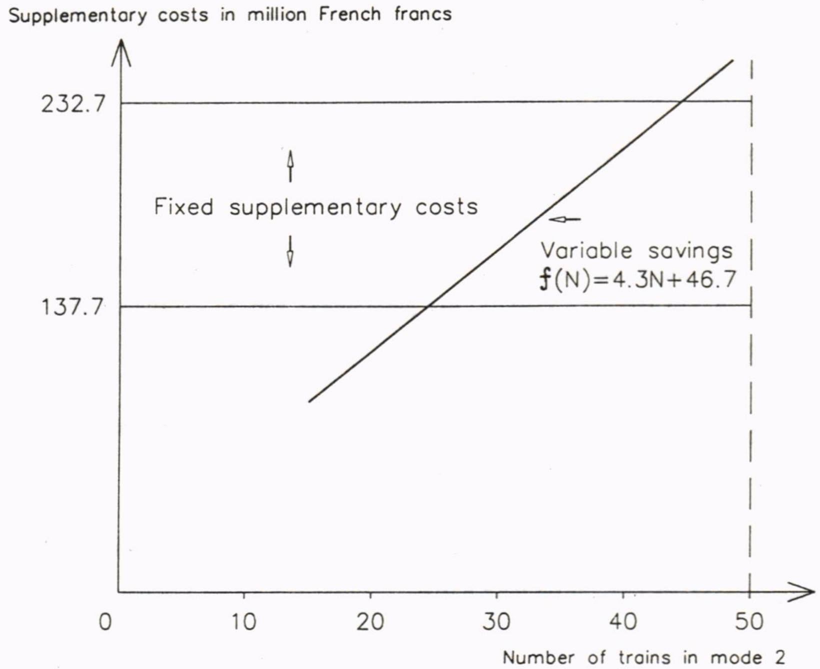
- the fixed part: If we take into account the cost of additional testing and integration period, the total supplementary cost of mode 2 is 232.7 million French francs. If the cost does not be taken into account, it will be 137.7 million French francs.

- the variable part connected with the volume of vehicle fleet: $f(N) = 4.3N + 46.7$

The figure 2 shows that, if we take into account the cost of additional testing and integration period, the financial consequences are positive when the number of trains equipped in mode 2 equals or is more than 44. It means that the fully automatic urban mass transit system will be a better choice on a line where the frequency is one train per 63 seconds for a service of long period. It must be noted that the minimum practical headway that the VAL system can be arrive is one train per 60 seconds.

On the other hand, if the cost of additional testing and integration period does not be taken into account, this threshold falls to 22 trains corresponding to a minimum service interval of 132 seconds.

Figure 2: Variations of the financial consequences of second comparison with the volume of vehicle fleet (over 60 years with a discount rate of 8%)



4. THIRD COMPARISON: a fully automatic line with short and small trains, and a one-man operated conventional metro line with large and long train

In order to distinguish the cost/benefit of a fully automatic mini-metro line to that of a one-man operated conventional full-scale metro line, we proceed to the third comparison.

In this comparison, we compare the mode 2 of the first comparison with the mode 1-2: identical to mode 1 in the first comparison, but with a train of 4 large cars of VAL-256 type (the width of cars is 2.56 m) and a lower service frequency.

On the line comparable to the line 1 of Lille's VAL, the main items in the financial assessment are the following:

- Infrastructure investments: With the results of the calculation of RATP, the supplementary cost of infrastructure of mode 1-2 is estimated at 435.4 million French francs.

- Rolling stock investment: The train unit capacity in mode 1-2 is much more higher than the one in mode 2. For the same traffic and lower service frequency, the mode 2 must be equipped 2 supplementary trains of 2 cars. On the other hand, there are 20.7 million French francs of supplementary cost of on board ATC equipment in mode 1-2.

- Fixed equipment investment, study and testing investment, and the cost in mode 2 for 4.5 months of additional testing and integration period: It is reasonable to suppose that the situation is identical to the first comparison.

- Operating staff costs: Considering that the minimum interval of mode 1-2 is about 135 seconds and the maximum one is reduced to 13 minutes 30 seconds, the number of drivers is 63. It needs therefore 5 train dispatchers and 2 direction staff. It is noted that the minimum headway in mode 1-2 is more than 100 seconds. As the situation in second comparison, no train reversal aid agent is requires and there are 17 agents in terminals.

- Supplementary maintenance costs other than staff costs: (1) Rolling stock maintenance: 4.27 million French francs per year in mode 2; (2) Station maintenance: 5.80 million French francs per year in mode 1-2; (3) Fixed equipment: 3.03 million French francs per year in mode 2.

Similar to the second comparison, we suppose that the average lifetime of civil works is 60 years. In the meantime, the lifetime of system equipment remains 20 years, so we must renew all of them 2 times over these 60 years.

The financial consequences of third comparison are presented in the table 6, and the variations of these consequences with the volume of vehicle fleet are presented in the figure 3. We observe that the fully automatic transit system is always the best choice, with any discount rate and even though the cost of additional testing and integration period is taken into account. It is obvious that in the third comparison, the savings on infrastructure by adopting short and small trains play a very important role in the financial assessment. It is more important than the financial effect of the additional testing and integration period of fully automatic systems, and also more important than the savings on on-board ATC equipment and drivers by choosing large and long trains.

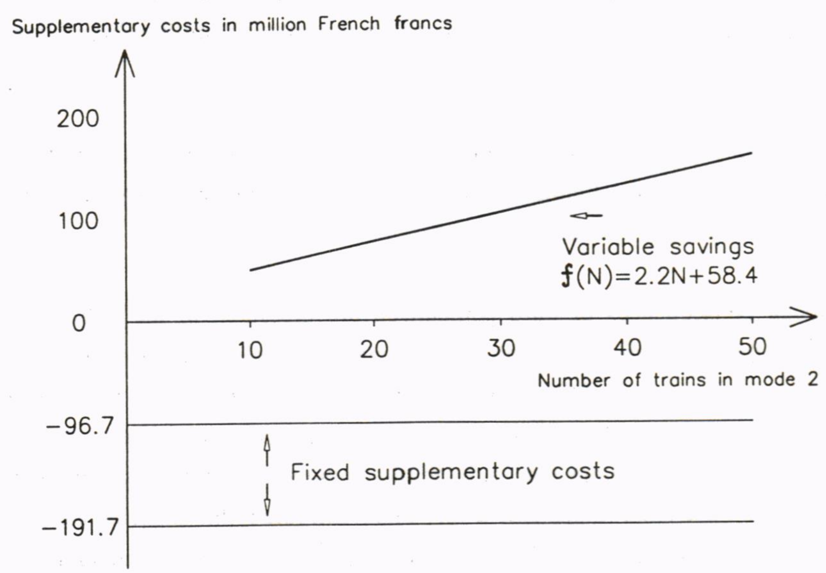
It is noted that the high service frequency is attractive to the users of urban public transportation. It means that the mode 2 will probably get more annual revenue in comparison with mode 1-2 and that the consequences will be more favorable to mode 2.

Table 6: Financial consequences of the third comparison over 60 years

Discount rate	Benefit updated over 60 years (million French francs in January 1995)	
	a	b
5%	+ 407.7	+ 312.7
8%	+ 364.9	+ 269.9
10%	+ 346.5	+ 251.5

* a: without taking into account the cost of additional testing and integration period;
b: taking into account the cost of additional testing and integration period.

Figure 3: Variations of the financial consequences of third comparison with the volume of vehicle fleet (over 60 years with a discount rate of 8%)



5. CONCLUSION

The main conclusion of this study, according the results of three above comparisons, is that if we choose as reference the configuration of the line 1 of Lille's VAL, with the same transport supply, in all the cases, the financial consequences are favorable to the mode 2, a fully automatic urban mass transit system VAL with short trains and small vehicles, in comparison with one-man operated metro systems which are equipped with a conventional ATO system such as that of the Paris Metro: mode 1, mode 1-1 and mode 1-2.

In the third comparison, the financial consequences are the most favorable for the complete automation. The supplementary investment of infrastructure due to the widening and the lengthening of trains is very heavy and can not be made up by the savings on the ATC equipment and on operating employees.

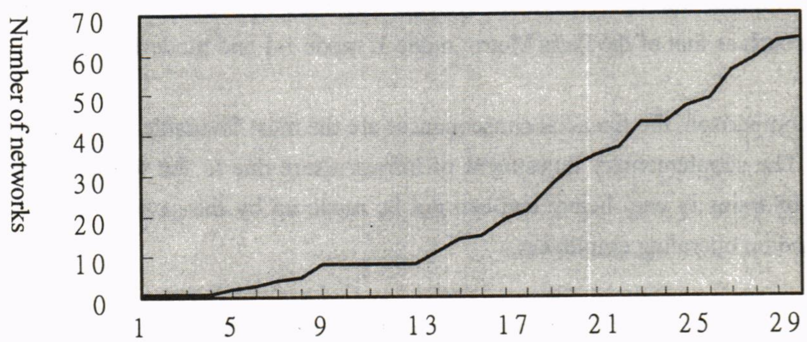
The financial consequences of first comparison are in the second rank. There is a minimum fleet threshold for fully automatic line: 30 trains corresponding to a service interval of 95 seconds in the peak hours. It appears that the fully automatic mode of operation is the better choice, in view of cost/benefit, as far as this threshold is reached.

It is clear that the financial consequences of second comparison are less favorable to mode 2, and the consequence is even negative if we take into account the supplementary cost due to the necessary additional testing and integration period of fully automatic systems. In relation to the first comparison, the supplementary investment of civil works connected with the lengthening of trains is not very high in comparing with the savings on drivers when the long trains are adopted. Nevertheless, if we take into consideration the attraction of high service frequency of fully automatic lines for urban public transportation users, we can imagine that there will be certain excess of annual revenue in mode 2. This excess of annual revenue will more or less compensate for the supplementary costs of fully automation.

In brief, following the results of this study, the fully automatic urban mass transit system is a better choice, on a cost/benefit basis, when a minimum fleet threshold is reached or, when the line running with a high service frequency during the day. Moreover, such an operating mode yields also a better quality of service in terms of frequency, regularity and safety, as well as greater flexibility of operation.

All these reasons probably explain why more and more new urban transport systems with entirely automatic operation put into service in different countries and cities (see Figure 4), and why more and more people begin to accept the complete automation as an "irreversible" trend in the field of urban public transportation.

Figure 4: Development of fully automatic urban transit networks



Accumulated years from the opening of the first fully automatic transit line in 1967

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