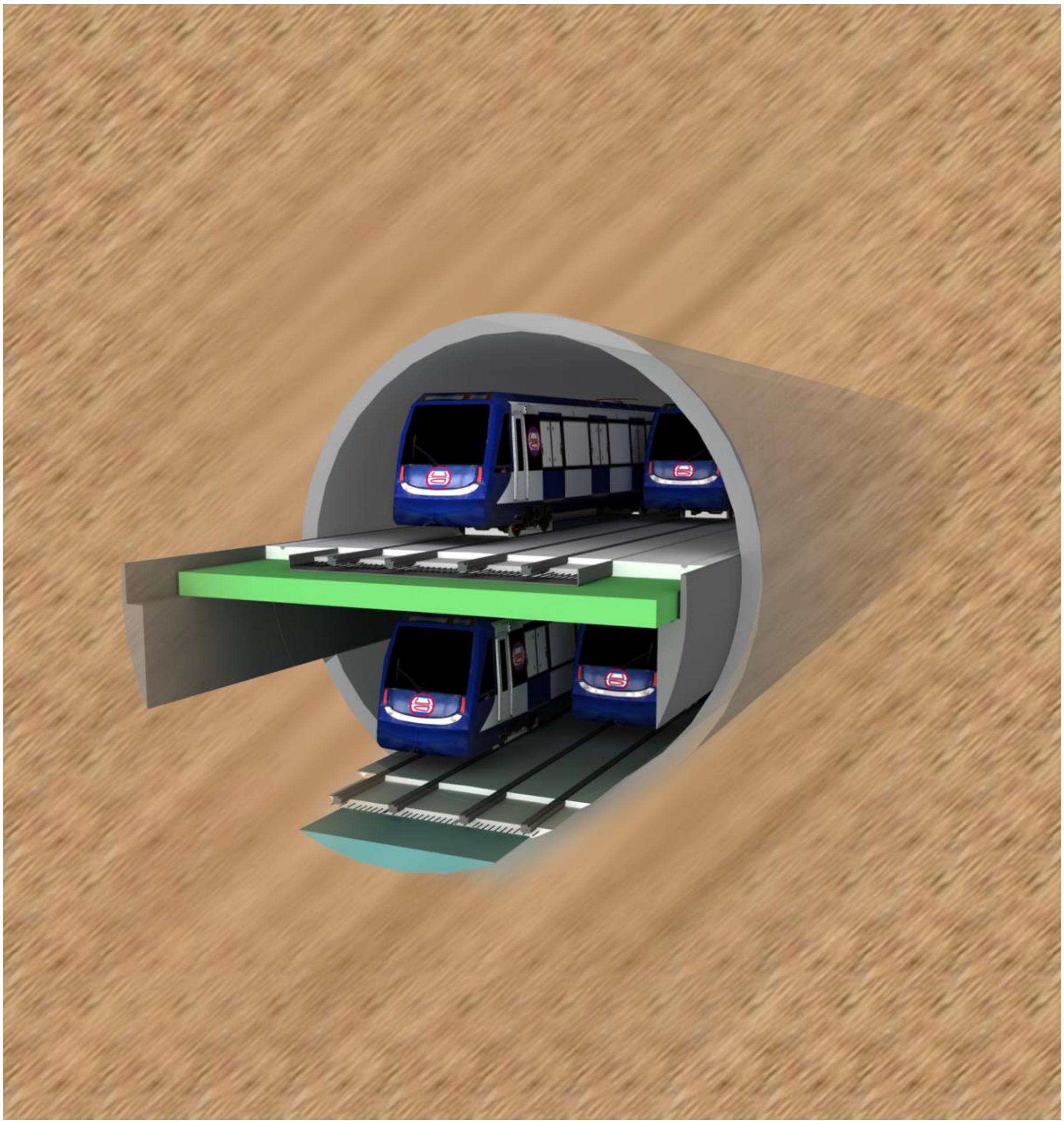
MetroDuo



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0. Summary.

This article describes a new high-capacity, high-speed public transport alternative that responds to the mobility problems faced by large cities, where the distances travelled are ever-increasing and travel time has become a decisive factor for guaranteeing the inhabitants' quality of life, the city's competitiveness and hence its sustainability. The analyses conducted by different departments of Metro de Madrid have been used to prepare this report.

1. Introduction

Demographic trends indicate that the process of concentrating a large part of the world's population is going to continue. It is expected that by the 2025 there will be more than 20 cities with populations in excess of 10 million inhabitants and another 20 with more than 5 million.

At least in the short and medium term, the difficulties with harmonizing territorial and urban development policies and measures in order to reduce the number of mechanized trips required or the distance travelled will inevitably lead to high levels of mobility over the next 20 years, which will continue to increase.

The heightened use of Information and Communication Technologies (ICTs) should help to limit that growth to a certain extent but even so the increased amount of time dedicated to transport will have a high social cost that will have negative effect on the quality of life of the inhabitants of these cities and their competitiveness, putting their sustainability in jeopardy. Consequently, the challenge to reduce the time needed to move around in large cities becomes one of the key aspects to guarantee the survival of these cities.

Not only will the distances travelled by the inhabitants of large cities continue to expand but the number of people affected by this negative phenomenon will also increase. Economic and social costs will shoot up and a significant portion of GDP will be allocated to mobility which, as a business activity, is not productive for society and, far from having a positive impact on a city's prosperity, has other social and environmental ramifications.

In this situation, the metro will continue to be an essential mechanism for resolving mobility problems as part of the integrated transport system in which intermodality and and interchanges will continue to be vital. However, for large cities these problems will change radically in terms of their dimension. One can easily envision overcrowded cities occupying hundreds of square kilometres of space. These would be polycentric cities with high-intensity transit corridors and urban routes in excess of 100 kilometres.

Reducing the amount of time needed to move about as one of the factors affecting a large city's economic development is an objective that has always been part of the metro's mission. It is also a concern of the European Union, as attested to in the White Paper proposing measures to break with the binomial which holds that "as economic growth increases so does the mobility and congestion in cities". Notably, one of those measures includes fostering the use of public transport and making it ever more efficient.

However, metro lines and networks as we know them today cannot efficiently resolve these problems for the following reasons: a) experience shows that as lines are made longer commercial speeds tend to decrease, as a consequence of which travel times increase; b) despite the application of state-of-the-art rail signalling and trains equipped with advanced technologies, the improvements to commercial speeds are insufficient, even in the case of automatic lines; c) the travel time and average distances travelled by users continue to rise as a consequence of the expansion of urban and metropolitan areas.

Therefore, we need an alternative solution that increases current travel speeds, commercial speeds in the case of the underground, as a means of reducing travel times. Such a solution must, at the same time, meet the expectations of the users of conventional metro networks by offering the capillarity that guarantees extensive coverage and therefore easy accessibility. However, the latter aspect, which entails having a station within a radius of several hundred metres (between 600 and 800 metres on average for new lines) would penalise commercial speeds due to the number of stops/stations that would be required.

Making the increased commercial speeds that would reduce travel times compatible with the high capillarity that guarantees the extensive coverage of metro networks is the motivation behind the proposal to create the dual line which we have called MetroDuo and which is described in this document.

Up

Down

A line Down, another Up
and both in One tunnel

MetroDuo Logo

The following sections explain the results of the basic studies conducted to analyse the viability and profitability of the proposed solution from a social, economic and environmental perspective. We will compare the travel times of a dual line and conventional line and the investments and maintenance required in both cases.

2. Configuration of a dual line. The MetroDuo.

The MetroDuo, a dual underground line, is composed of four tracks that share a common infrastructure to travel through tunnels and stations.

The four tracks are grouped in twos and arranged on two different levels. In reality, they are two separate but superimposed lines, with the same track interconnected at the stations, which they also share.

These two lines have different operating characteristics. Whereas the characteristics of one of them, which we will refer to in this document as the local line, will be those of a conventional metro line with stations every 600 to 800 metres, the other line which we will call the express line will only stop at certain stations to guarantee a much higher commercial speed.

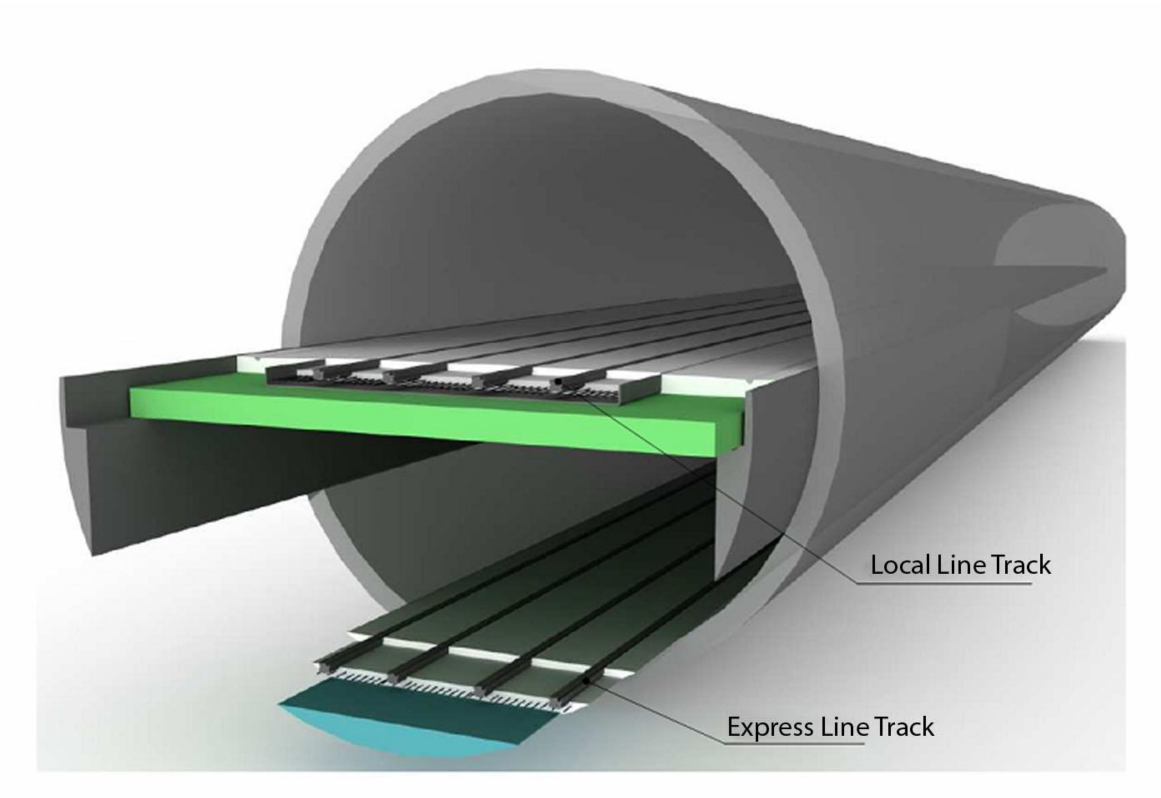


Figure 1: View of the tunnel section

The local line will continue to guarantee high levels of accessibility to the network while the express line will offer much higher average travel speeds than are currently available. Unlike the traditional metro line, with the express line the time savings will increase as the distance travelled increases.

The express line would be on the bottom and the local line on top. There are numerous reasons for this, some of a functional nature and others of an environmental nature. There are two important reasons from a functional point of view. First of all, unless there were a serious imbalance between the number of express and local trains entering and exiting the station, a larger number of clients would be forced to walk further to get to their platforms. Secondly, because otherwise, passengers would have to go through the express line area to get to their platforms and in those stations where the express line does not make a stop, the finish work and outfitting would not have to be as detailed as would normally be the case to serve the intended purpose.

The environmental reasons have to do with minimising noise and vibration levels. Although elastic fastening and suspension systems would be used in the track design, it is only logical to assume that the express lines would be noisier and would vibrate more due to reaching higher speeds than the local trains. Therefore, the source of the noise and vibrations should be as far away as possible from the building foundation to reduce the disturbances caused by the noise and vibration. Likewise, as we will see below the speed at which the express line trains pass through the stations, even if they do not stop there, will cause air movements which can be controlled more easily if the express line occupies the bottom position.

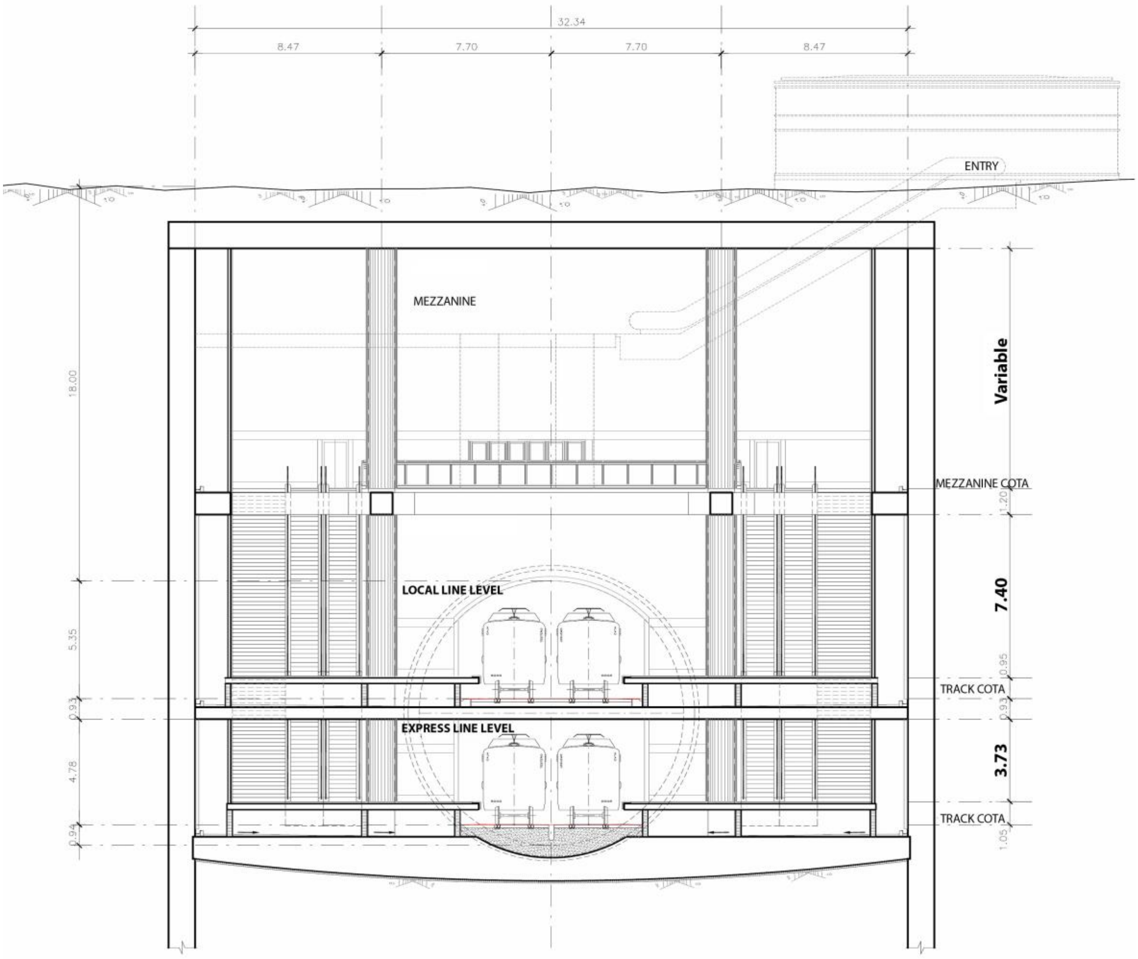


Figure 2: Details of a section of a station

The dual line can be used for various types of travel depending on the origin and destination of the trip:

a) Trips that start and end at local line stations and which, due to the short distance to be travelled, do not require a transfer to the express line since there would be no considerable time saving. The journey consists of just one leg that uses the local line only.
b) Trips that start and end at local line stations where there is no express line. In this case the distance to be travelled is long enough to justify an intermediate leg of the journey on the express line. The journey therefore has two legs, two on the local line and one on the express line, and requires two transfers (from local to express and from express to local).
c) The trips that start and end at a local line station which is also an express line station. In this case, the entire trip consists of just one leg on the express line.

d) Trips that start at a local station and end at a station with an express line or vice versa. In this case, the journey consists of two legs, one leg on the local line and the other on the express line with just one transfer (from local to express or vice versa).

When estimating the travel time, we considered not only the actual travel time inside the train but also waiting and transfer times.

Obviously, the social value of a dual line compared to a conventional line, which is largely determined by the amount of time saved, depends on three fundamental parameters:

1) Demand level in the corridor
2) The distribution of demand in the corridor
3) Distances travelled

The results of the parametric analyses are set out below along with a series of advantages associated with the versatility and flexibility offered by the operation of this type of dual line, which undoubtedly redounds to improvements in the safety and quality levels of the services.

3. Constructive and structural aspects

As important as the functional aspects of the solution presented here are, its constructive viability is no less important. The tunnel of a dual line can be built safely, simply and rapidly using mechanized excavation technologies and tunnel-boring machines with diameters similar to those we are using or have used in the past on different projects, in both soft earth and rock, to accommodate two dual-track lines in a single tunnel section.

While the alternative described here includes the use of tunnel-boring machines, obviously other tunnel-building methods are just as valid.

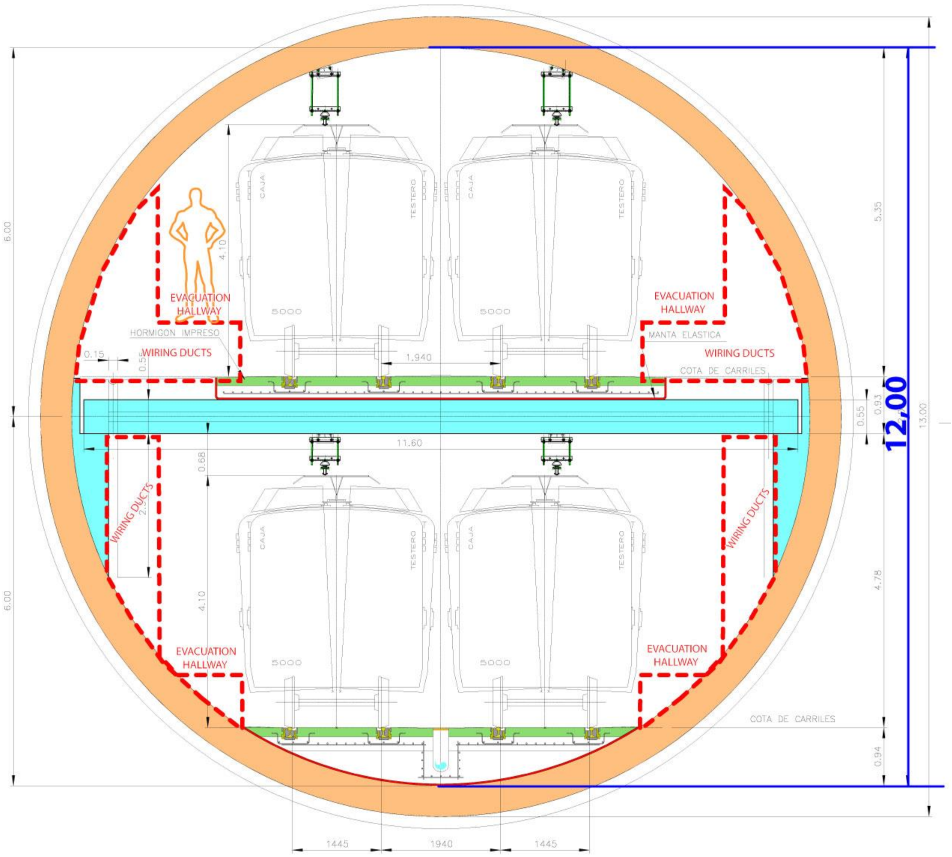
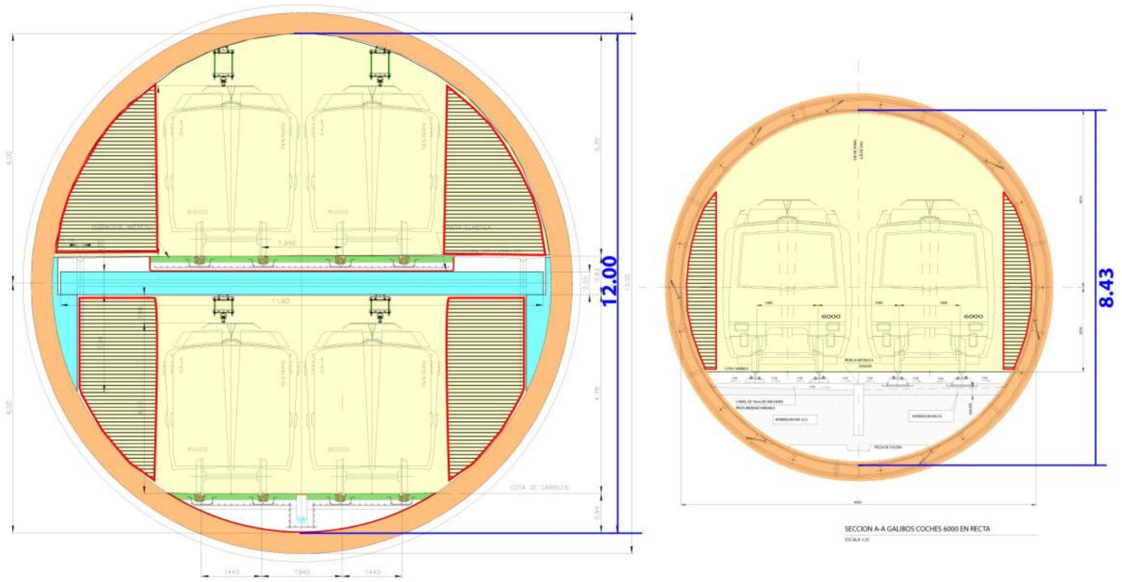


Figure 3: Predesign of tunnel section.

In this case, we have designed a circular tunnel section based on the results of the analysis to determine the kinematic clearance gauge of the trains with a platform width of 2.80 metres and a minimum curvature radius on the track of de 250 metres.

Figure 3, which shows a predesign of the tunnel section, also shows some of the design characteristics such as an interior free diameter of 12 metres, although an 11.5 metre diameter would also be possible. The manufacturers of tunnel-boring machines we consulted confirmed the possibility of designing the minimum curvature radii mentioned above with these section dimensions.

A particularly relevant aspect is the ability to make the most use of the tunnel section. For an 8.43 metre section of a conventional line, the tunnel use, taking the clearance gauge of the trains into account, is 67%, while for a 12 metre section of MetroDuo tunnel, it is 79%. The usable space for an 8.43 metre section of tunnel, not counting the top part which is only used for powering the train, is 5 m^2, while for a 12 metre section of MetroDuo tunnel it is 24 m^2. In the latter case, this space would be used for evacuation routes and to run wiring, as seen in figure 3.



	Tunnel 12.00 m. (MetroDuo)	Tunnel 8.43 m.
Use of the Tunnel section	79%	67%
Usable space available	24 m^2	5 m^2

Figure 4: Detail of the use of the tunnel and available space

Surely the experience and know-how acquired by Spain, and particularly Madrid, in construction projects using tunnel-boring machines in urban areas is unsurpassed in the world. It is well known that the contribution to this made by Manuel Melis, former Chairman of Metro de Madrid, who promoted the use of these technologies, was decisive. A variety of tunnel-boring machines have been used, ranging from the small diameters needed to excavate collectors and services tunnels, to larger diameters needed to build metros (6-9 metres) and even larger ones to build the M30 (more than 15 metres). There is no doubt that excavating with tunnel-boring machines of the diameters proposed herein would not pose any problem or risk whether excavating in rock or soft soil.

Furthermore, the cumulative experience acquired in tunnel construction demonstrates that the excavation speed does not decrease considerably as the section size increases; hence, it would seem logical to affirm that the dual line tunnels excavated using tunnel boring machines can be completed with outputs similar to those that have been obtained in the past: approximately 600 metres of tunnel per month. A single tunnel-boring machine could excavate 15 km of tunnel in two years.

The type of soil determines the minimum depth at which the tunnel should be excavated to avoid subsidence. When dealing with soft earth, the general rule is to situate the keystone of the tunnel at a distance of 1.5 times the excavation diameters. Therefore, the elevation level of the upper line would be approximately 24 metre deep and the lower level 30. The corresponding platforms would be approximately one metre higher, i.e., 23 and 29 metres deep, respectively. These depths could be reduced depending on the quality of the earth to be excavated and the soil treatments applied in this regard.

The configuration of the stations would be similar to those designed for previously enlargements of the Madrid Metro network. These are dual stations and the design criterion for all of them, regardless of whether or not the express line would stop at them under normal operation conditions, the lower level would be finished and outfitted in such a way as to make it usable in exceptional or emergency situations, thus offering flexibility to line operations and evacuation procedures. These stations would therefore include platforms, normal and emergency staircases, lighting and all of the systems that would make it possible of the lower level of the station to be used as safely as the conventional line level, but with limited conveniences.

In any event, it must be possible to make the necessary changes in the future, easily and without affecting train operations, to transform these stations into stations with express line stops were this to become necessary due to changes in demand. In short, the geometry of the stations with only local train stops and the stations with both local and express line stops is the same. However, the finish work and outfitting differs from the express line or lower level of the stations to the local line or upper level.

There are two types of stations: type 1 with local line stops and type 2 with both local and express line stops. The fact that both stations share the same geometry allows a type 1 station to be converted into a type 2 station, merely by making certain additions to the existing stations.

Not only does the design criterion for access to the stations provide for a fast and easy interchange between the two levels at stations with both types of lines but also the most direct possible entrance to the lobby. A platform length of 120 metres was considered, although this could vary depending on the rolling stock to be used.

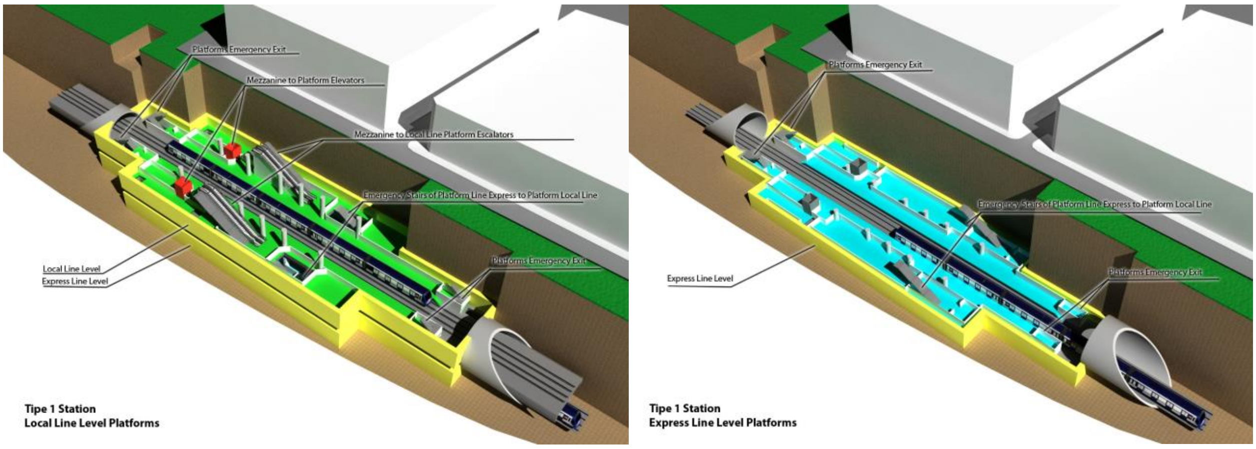


Figure 5: Detail of a type 1 station

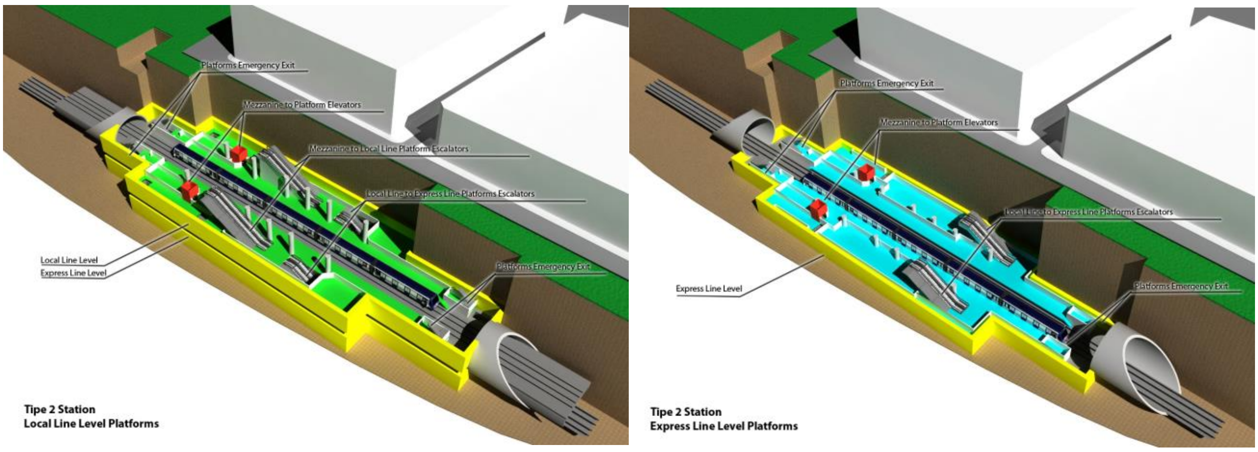


Figure 6: Detail of a type 2 station

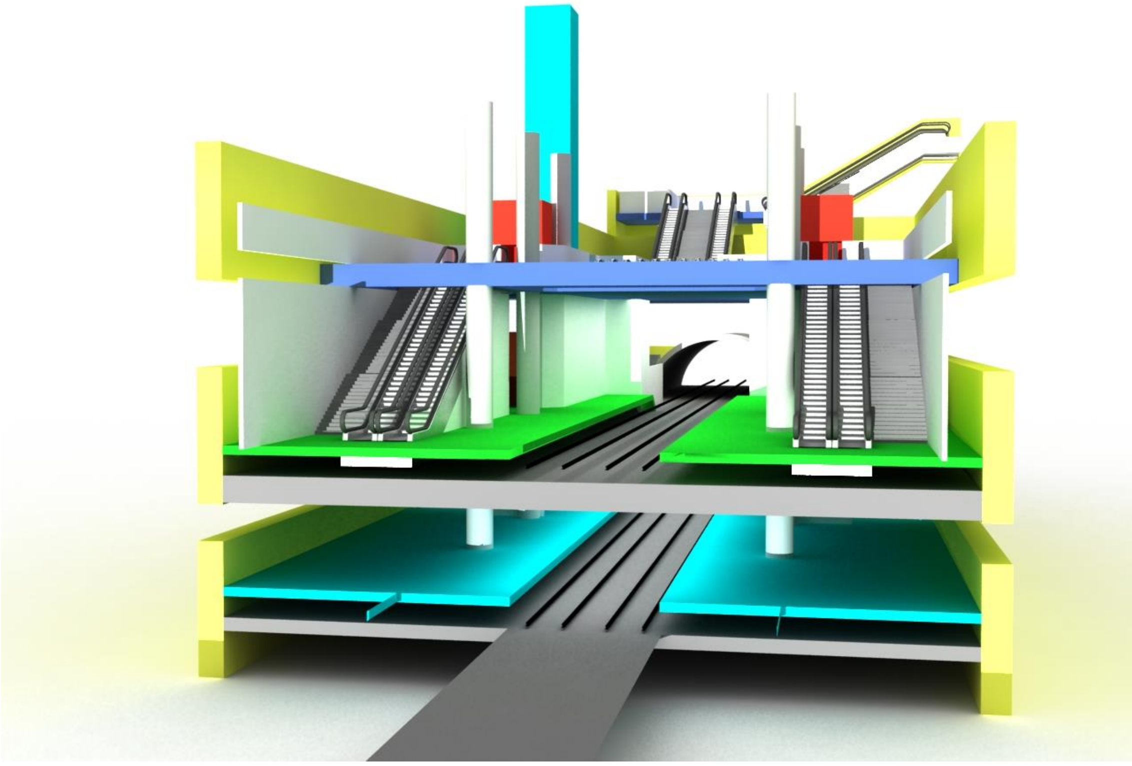


Figure 7: section of type 2 station

The width of the stations would be similar to the widths of the stations built in recent years in Madrid. Since tunnel diameter does not condition the width, these widths are considered sufficient to accommodate the movement of a high number of people, although in some cases where demands levels are extraordinarily high it may be necessary to make them even larger but adhering to the same functional criteria.

4. Travel time. Parametric analysis.

The travel times for MetroDuo have been calculated and compared with those of a conventional line. In order to simplify the analysis, we assumed that the train tracks would be straight and even and that there would be a local line station every 700 to 1000 metres.

We also established certain kinematic features which were identical for both local and express lines. One of the aspects which would afford the greatest operating flexibility to a project of this kind is that the trains can run on one line or the other interchangeably, switching levels at the MetroDuo line terminal which would be facilities where both types of trains can be serviced, maintained and parked.

The maximum train speed would be 110 Km./h, limiting the speed of the express line trains as they pass through stations where they do not stop to 60 Km./h. This speed could be increased if specific design measures were taken at these stations to control air speed.

We analysed cases in which there would be a station with an express line stop every 4 stops on the line and every 5, 6 and 7 which assumes distances between stops on the express line of 2.8 km, 3.5 km, 4.2 km and 4.9 km for scenarios in which there is station every 700 m on the local line and similarly for distances of 1,000 metres (4, 5, 6 and 7 km.).

For all of these cases the travel times were simulated using the conventional line only (equivalent to using only the local line on MetroDuo) and using the two line types offered by MetroDuo, based on the different types of trips described in Section 2.

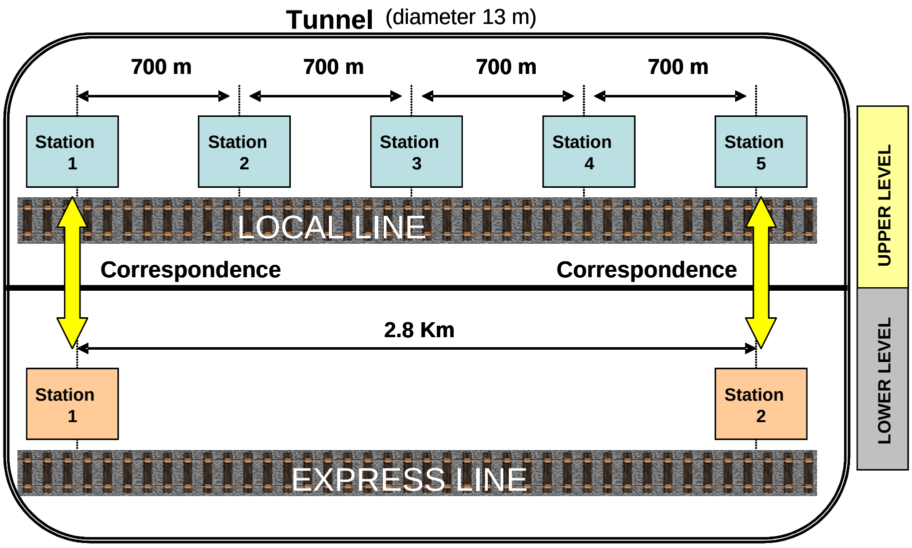


Figure 8: Configuration of the Metro duo line with stations every 700 metres

These simulations took waiting times on the platform into account as well as time needed to switch from one line to another, time stopped at stations and travel times inside the trains.

Chart 1 refers to the configuration shown in Figure 8, with express line stations every 2.8 km.

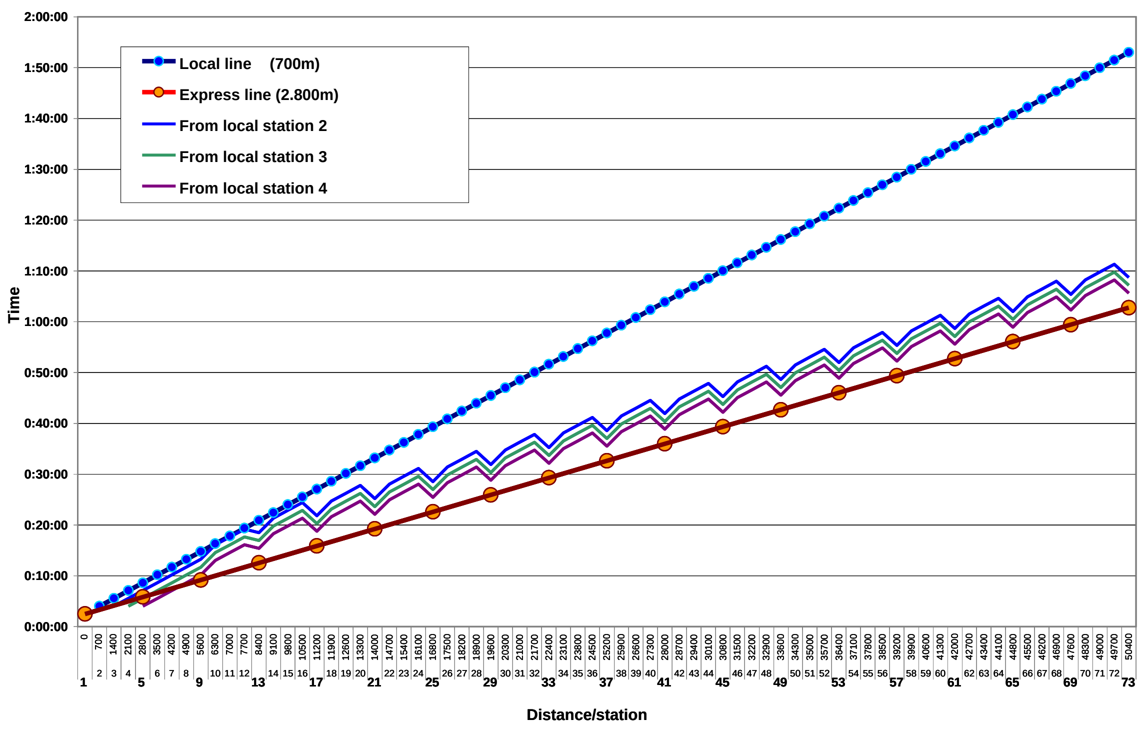


Chart 1: Combine travel time between stations of a 50.4 km long MetroDuo line with distances between local stations of 700 m and 2,800 m for express stations (1 express for every 4 local)

As seen on the chart above, for each distance there is a maximum travel time which is based on the commercial speed of the local line (or conventional lines) and a minimum travel time which is based on the commercial speed of the express line. Obviously, in the latter case the values only make sense when the distance refers to the position of a station with an express line stop. The saw tooth curves express the travel times for combined journeys which start or end at a local line station.

Below is a comparative analysis of the travel times for interstation distances of 700 and 1000 m.

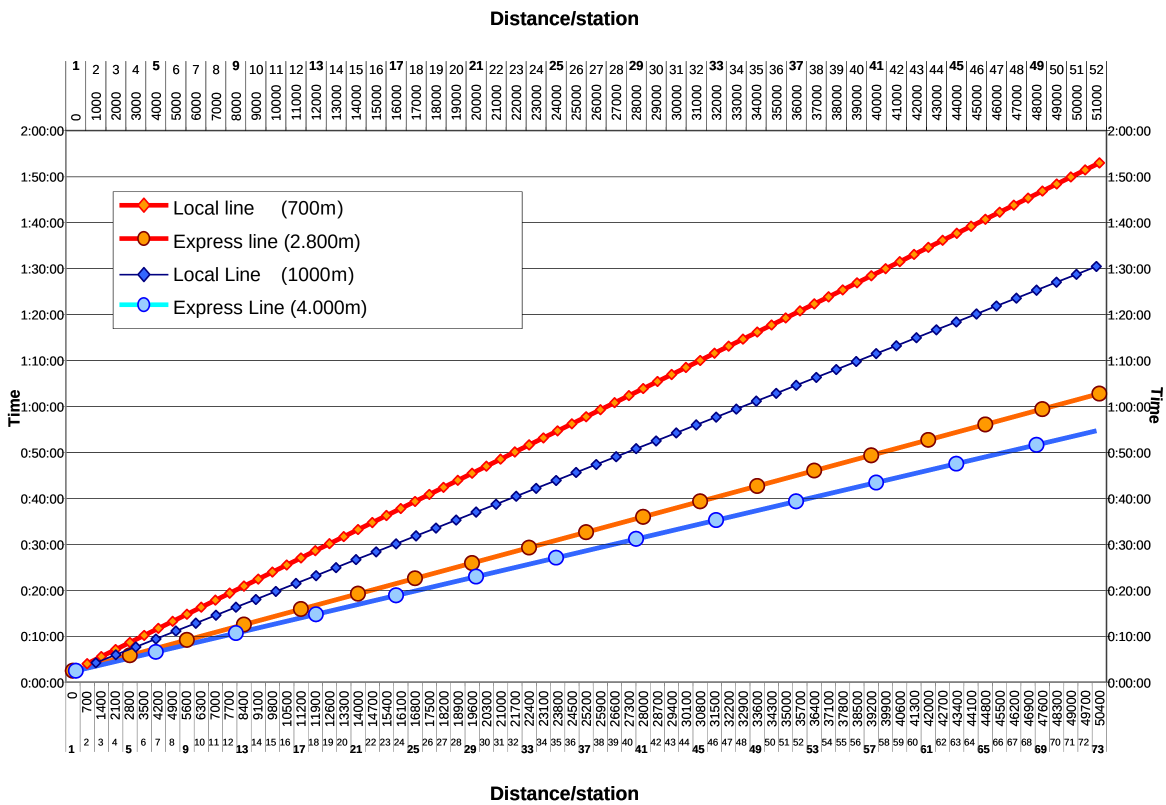


Chart 2: Travel time between local and express stations on a 50.4 km MetroDuo Line with distances between stations of 700 an d 1000 m. (1 out of 4)

Chart 3 shows the travel times when the distance between stops on an express line is 4.9 km.

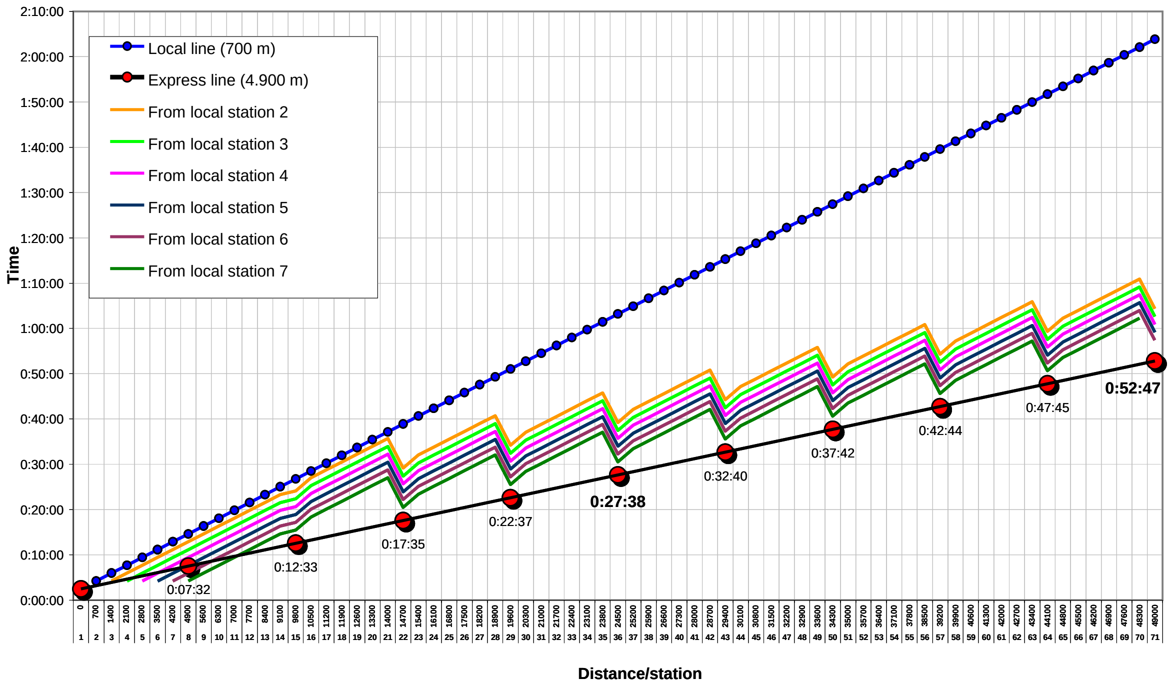


Chart 3: Travel times between stations on an Automatic Line and a 49 km MetroDuo line with 71 stations and 1 out of 7

Based on the results it can be concluded that:

1.- Except in those cases where the entire trip takes place on an express line, the average time savings are notable after 5-10 km.

2.- Greater distances between stations on the express line mean higher commercial speeds (with a decreasing line slope for the express line), but slows down the travel time for combined journeys (increasing the value of the peaks of the saw tooth curves).

The analysis presented below refers to the first scenario mentioned above, i.e., one in which the distance between local line stations is 700 metres and the distances between express line stations is 2,800 metres.

The line length considered is 50 km. This hypothesis would seem to be reasonable for the type of city under consideration. There are already lines this long in the world and even longer in some cases such as London where we see lines that are more than 70 km long. In Madrid, we are close to reaching that length, although with ruptured demand in some places (MetroSur, line 9, line 10).

5. Demand model and quantification of time savings

The comparison of line capacity, travel times, energy use and other factors is based on the comparison of a MetroDuo type line and a conventional line equipped with the most highly advanced technology operating automatically, i.e., a line which offers the maximum transport capacity and the maximum commercial speed according to the current state-of-the-art.

To determine the viability of the line we must first build a demand model. To do so, we looked at the data on the underground systems of some of the world’s largest cities with mobility problems of the kind which the MetroDuo seeks to resolve, with high demand, high levels of train occupancy and some lines nearing the saturation point. Specifically, we considered the data for the underground systems operating in Moscow, Sao Paulo, Santiago de Chile, Mexico DF and Tokyo.

Image of the Sao Paulo metro

Taking the average number of passengers per kilometre for these systems and applying the numbers to the line under study (50 km long), we obtained a total weekday demand of 1,090,000 trips. For this demand, we estimated a maximum rush hour intensity for the busiest segment of 43,600 passengers per hour and direction.

A conventional line operating with an ATP system and automatic speed regulation (ATO) in the current state of the technology has a transport capacity of 30,000 passengers/hour based on the moving stock mentioned above, which means that it would not be possible to meet the target demand since the line would have to run at 145% of capacity. It is therefore necessary to accept much higher levels of occupancy than the design levels (6 passengers /m^2).

	Automatic Line	Local / Expres (same capacity)		
		Local	Express	Trains / Total Capacity
Comercial Speed (km/h)	27,04	26,76	48,18	
Round trip time	3h. 43'	3h. 46'	2h. 5'	
Average interval between trains (sec.)	105	262	175	
Number of trains	**128**	52	43	**95**
Transport capacity (passenger/h.)	**43.611**	17.478	26.167	**43.645**

Table 1: Operating data for an automatic conventional line and MetroDuo

For the same transport capacity, 43,600 passengers per hour and direction, 95 trains would be required with the MetroDuo solution as opposed to the 128 for a line operating automatically without a conductor. However, the most important difference between one solution and the other is that while the automatic line would be on the brink of maximum capacity, there is room to increase MetroDuo's capacity either by running more trains or outfitting them to operate automatically. Without automation, MetroDuo could run 145 trains with a capacity of 61,056 passengers per hour and direction, which is 40% more capacity than an automatic line, and up to 204 trains if both the local and express lines were automated, in which case it would have a capacity of 87,223 passengers per hours and direction, i.e., double the capacity of a fully automated line without conductor.

Based on the available data for the underground systems mentioned above, we also calculated the average hourly distribution of demand for incorporation into the analysis.

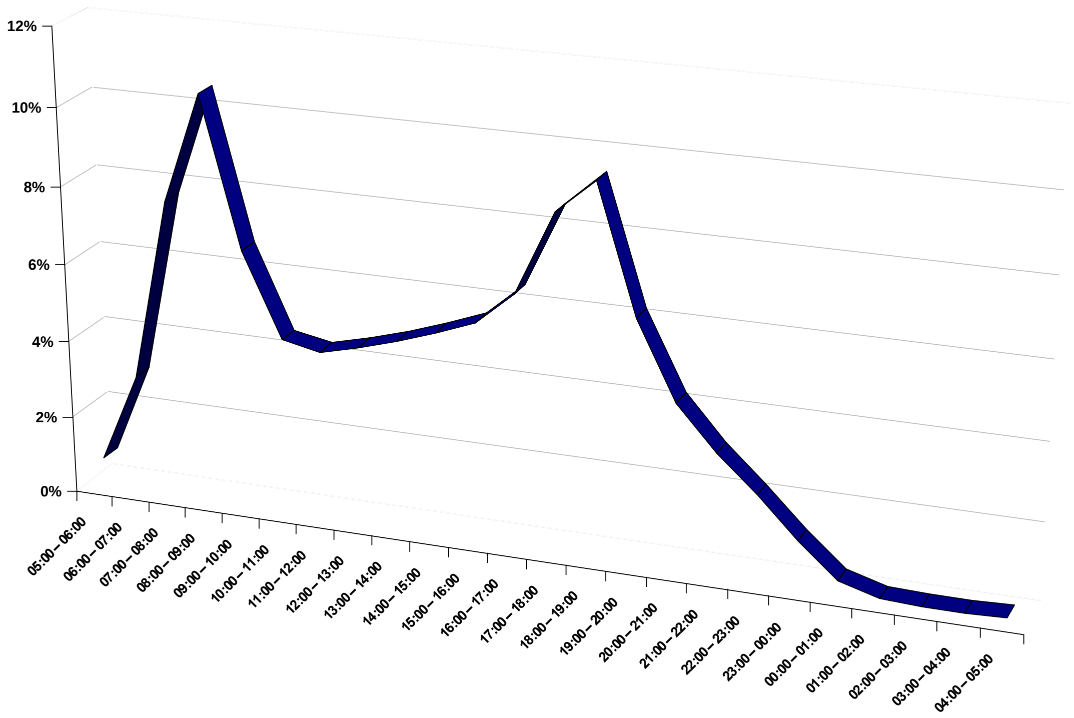


Chart 4: Average hourly distribution of weekday demand for the world's leading undergrounds

The total estimated demand of 1,090,000 trips for a weekday is broken down into time slots as shown on Chart 4.

The demand and maximum intensity values are by no means disproportionate. They amount to a density per kilometre of 21,626 passengers. A new line is due to open shortly in Sao Paulo with 14 km of track and 15 stations, with a maximum rush hour intensity on the busiest segment of 72,000 passengers per hour and a density of 85,714 passengers per km of track. Not all of the stations will become operational until these values can be attenuated.

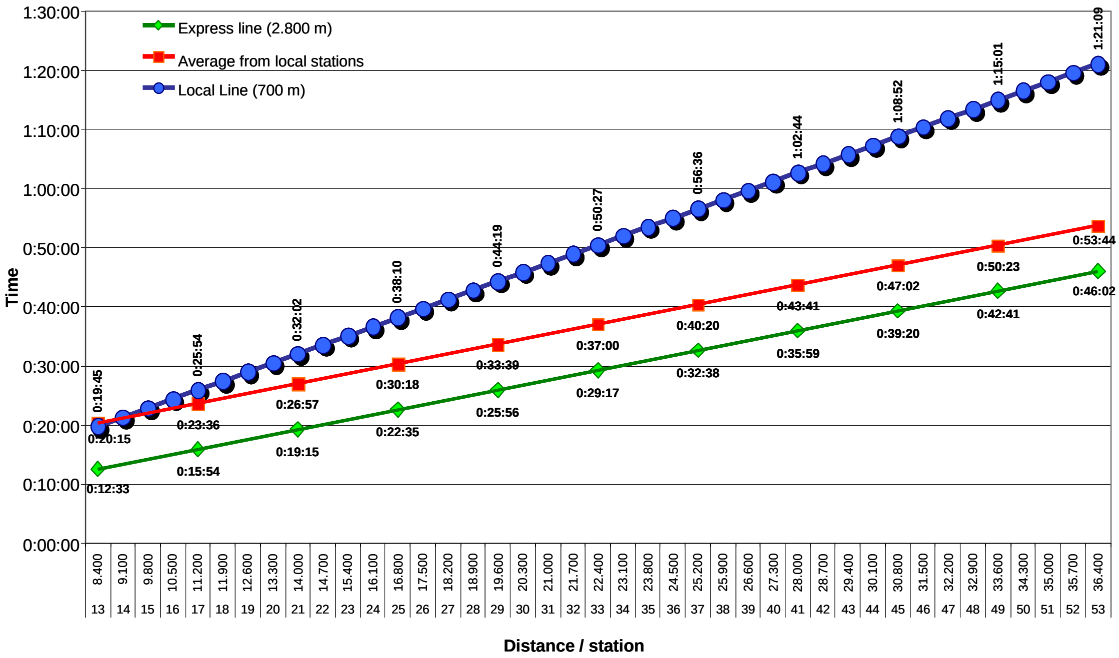


Chart 5: Travel times for interstation distances of 700 m. (1 express stop every 4 local stops)

The lines on Chart 5 show the travel speeds resulting from the simulation of an automatic conventional metro line and a MetroDuo line. For the MetroDuo line the information is split into two parts: the green line shows the commercial speed for trips using the express line only while the red line represents the equivalent average commercial speed using a combination of express and local lines.

The times are calculated as follows:

Tconventional = Distance/(Commercial speed)/60= Distance/27/60

Texpress = Distance/(Commercial speed)/60= Distance/48/60

Tcombined= T exp. + 7.5

NOTE: distances are expressed in kilometres and times in minutes.

To compare the time saving that would be achieved using one solution over another, we need to make a hypothesis about how demand is distributed between each one of the possible types of journeys and the average distance travelled on each trip.

We assumed that demand, as far as entrances and exits, is standard for all stations on the line except those which have both local and express stops, which it was assumed would be in a unique position either because of the number of passengers travelling through them or because of their relationship to the rest of the public transport system (connections to other lines, interchanges, etc.). To make allowances for this aspect, the weight assigned to these stations was double that assigned to the others.

Parametric analyses were also conducted to study travel distances. The results presented here refer to distances travelled of 14 and 20 km, in keeping with the characteristics of cities that are faced with the problem of covering such distances using conventional metro systems, as mentioned above. These average distances are similar to those currently covered by some metropolitan rail systems (e.g., Moscow).

Chart 6 shows the time that is saving by using MetroDuo compared to a conventional automated line based on the distance travelled and type of trip.

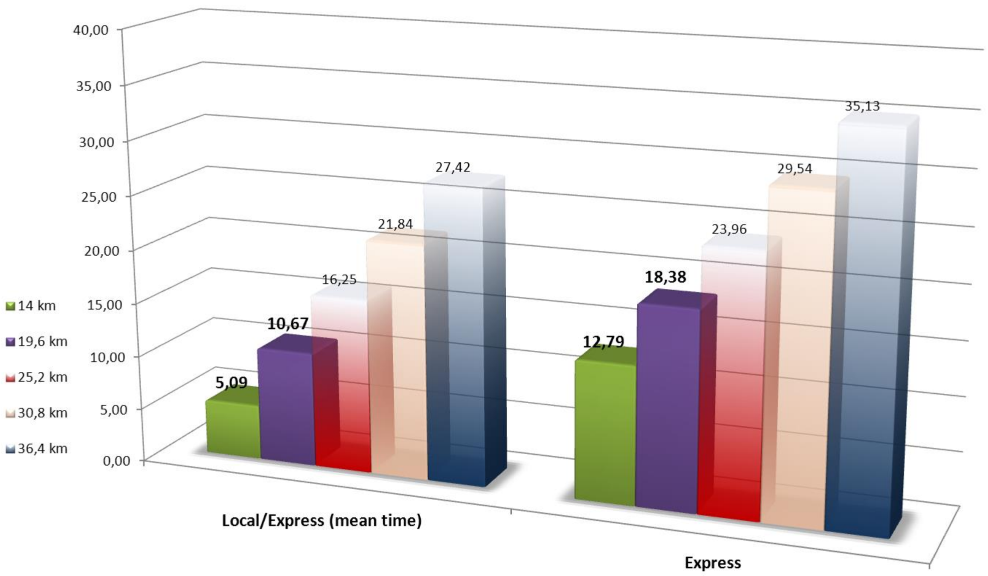


Chart 6: Time saved based on distance travelled

If we apply the time saving per trip to total demand for the line, we obtain the following annual savings, in hours, that would be obtained using MetroDuo compared to conventional automated lines.

Distance travelled (km)	Use	Saving (min)	Average saving per trip (min)	Total workday saving (min)	Workday saving (hours)	Annual saving (hours)	Cash saving (€)
14	Local/exprés	5,09	9,71	10.583.173	176.386	44.096.556	518.134.528
	Exprés	12,79					
19,6	Local/exprés	10,67	15,29	16.669.007	277.817	69.454.194	816.086.785
	Exprés	18,38					

Table 2: Economic value of annual hours saved

Only the savings obtained on weekday travel were considered (250 days/year) based on the daily line demand mentioned above (1,090,000 trips).

The monetarisation of costs discussed below, both the cost of time and the investment needed to build and commission the lines, is based on values applicable in Spain. To monetarise time savings, we used travel time to work which has different values. For this study we used a price of 11.75 €/hour[1].

[1] Value used in the Economic and Socio-environmental Report on Terrestrial Passenger Transport in the Community of Madrid in 2004. (updated to 2008)

6. Investment in construction and commissioning

The investment needed to put an automatic line into service with a maximum capacity of 43,600 passengers/ hour compared to a MetroDuo line with the same capacity, based on the line characteristics mentioned above, is discussed below.

The cost of a MetroDuo line, including infrastructure, installations, equipment and trains is approximately €6,023,000,000, which breaks down to a cost of €120,000,000 per kilometre.

The cost of conventional automated line, including the same items, is €4,424,000,000 which breaks down to an investment of €88,000,000 per kilometre. Therefore, the investment would be €1.600,000,000 more for the MetroDuo line compared to a conventional automated line, which represents an increase of 36% .

	Metroduo (1 expres-4 local)	Automatic line	Difference
Infrastructure cost (€ per km)	92.385.146	47.903.955	44.481.190
Cost of facilities (€ per km)	324.640	240.654	83.986
Total cost (€ per Km)	92.709.786	48.144.609	44.565.177
Total cost for 50.4 km line (€)	**4.672.573.213**	**2.426.488.299**	**2.246.084.914**
Cost of rolling stock: 6-car train (ATO) (€)	10.200.000		
Cost of rolling stock: 6-car train (UTO) (€)		12.000.000	
Trains: tranpsort capacity 43,600 passengers/hour including reserves	103	139	-36
Rolling stock cost(€)	**1.050.600.000**	**1.668.000.000**	**-617.400.000**
Cost of 2 depots - 70 trains (€)	220.000.000		
Cost of 2 depots - 70 trains (UTO) (€)		250.000.000	-30.000.000
Total cost (€)	**6.023.173.213**	**4.424.488.299**	**1.598.684.914**

Table 3: Difference in the investment required for an automated line and a MetroDuo line

7. Other economic, social and environmental aspects.

In this section we will discuss other economic, social and environmental aspects that contribute to the MetroDuo's ROI, in addition to the travel time saved.

Energy usage

The need for a smaller number of MetroDuo trains to satisfy the same demand volumes would save an estimated 34.20 GWh per year, with an economic repercussion of €3,077,919 €/year.

Time lost due to line disturbances

In addition, with two parallel lines operating at the same time less time is lost due to disturbances in the service because of incidents affecting one or the other. If one line is out of service, the other line can be used as an alternative. Unless both lines were to malfunction simultaneously, mobility in the corridor is always guaranteed. Applying the existing data on malfunction rates that measure the disturbances in metro service operations, we obtained the following values.

	Time lost to incidents (hours)	Economic value (€)
Conventional	1.094.396	12.859.151
Metroduo line	218.879	2.571.830
Time saving incidents	**875.517**	**10.287.321**

Table 4: Quantification of time saved on incidents

We considered the incidents affecting a conventional line with one track in each direction based on the model demand. It is estimated that the time lost for this reason would be reduced by 80%.

Decrease in greenhouse gas emissions

The reduced energy consumption referred to above will lower the emission of greenhouse gases.

Daily energy saving (kwh)	Annual energy saving (Gwh)	Economic value(€)	Annual emission reduction (TM)	Monetarization (€)	Equivalent trees
136.796	34,20	3.077.919	13.064	287.409	332.350

Table 5: Quantification of energy savings, lower emissions and equivalencies

Table 5 shows the value of the reduction of greenhouse effect gases. To obtain this value, we used the emission factor for the energy used by Metro de Madrid in 2008 to calculate the tons saved, at a price of 22 €/tons[2]. The table also indicates the number of trees needed to absorb these emissions.

[2] Value within the range recommended in the Impact study v 1.1. (Internalisation Measures and Policies for All external Cost of Transport) Feb. 08 with the participation of INFRAS (Universidad Karlsruhe)

8. The social benefits of MetroDuo. Investment return periods.

The annual return on investment defined in part 6 has been calculated considering the savings of an economic, social and environmental nature in a differential scenario referenced to the automated line, which are monetarised to analyse the profitability of the MetroDuo compared to the automated line:

- Travel time saved.
- Reduction of the impact of incidents.
- Reduction of energy usage.
- Reduction of greenhouse gas emissions.

	Economic value
TIME	
Annual travel time saved 14 km (€)	518.134.528
Annual travel time saved 19.6 km (€)	816.086.785
Savings from reduced impact of incidents (€)	10.287.321
ENERGY USED	
Annual saving from lower energy consumption (€)	3.077.919
Annual saving from reduction of greenhouse gas emissions (€)	287.409

Table 6: Calculation of annual return

Based on the annual savings obtained, the return periods are expressed below:

	Average distance travelled 14 km	Average distance travelled 19.6 km
Differential investment (MetroDuo - conventional line (€)	1.598.684.914	
Annual return(€)	531.787.177	829.739.434
RETURN PERIOD (YEARS)	**3,01**	**1,93**

Table 7: Recovery period.

9. Other advantages of MetroDuo

In addition to the advantage mentioned in section 7 above of ensuring service continuity by running two lines simultaneously, there are other safety-related advantages which are difficult to quantify but which undoubtedly add to the safety levels of these lines.

The existence of two different environments, one for each one of the lines, means that the two levels can be interconnected by means of the separation block using one of the levels as a safe evacuation route in the event of an incident affecting the other.

Furthermore, the space on the lower level of the stations without express line stops which is not used under normal operating conditions could play an important role in emergency evacuation planning.

Finally, the MetroDuo line optimises the use of equipment not on board the trains which could be shared by the two lines.

11. Conclusions

A new underground rail transport system called MetroDuo has been designed for use in large cities, whose benefits have been analysed on the basis of economic, social and environmental considerations. From this analysis, once reaches the conclusion that these alternatives offers substantial improvements to even the most highly advanced metro systems currently existing. These advantages are based primarily on a sharp reduction in the social costs linked to significant time savings. The following conclusions are reached from that analysis:

1.- For transport capacity levels higher than those allowed by automated metro lines, MetroDuo requires a 36% higher investment in infrastructure and commissions but offers great social and environmental returns on that investments.

2.- The savings which MetroDuo offers in relation to time and energy consumption compared to automated lines offset the investment differences within approximately three years, based on the most conservative estimate. After that time, for a 50 km line and the assumed levels of occupancy and distance travelled, the monetary value of the time and energy saved is estimated to be 530 and 830 million euros per annum.

3.- Under these conditions, while the capacity of an automated line with the same layout and length is exhausted and cannot satisfy possible increases in demand, MetroDuo has the ability to transport up to two times the number of passengers.

4.-MetroDuo is more energy efficient. Consequently, under the same conditions, it will emit 13,000 fewer tons of CO_2 per year less than an automated conventional line.

5.- MetroDuo can be safely and efficiently built and commissioned using procedures and technologies already existing on the market which are well-proven.

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