MISTER PRT- The Metropolitan Individual System of Transport on an Elevated Rail Personal Rapid Transit.

Basic system capacity and throughput analysis

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The purpose of this paper is to demonstrate the passenger carrying capacity of a MISTER system of transportation and how its stations, called stops, will easily absorb streams of passengers with minimum delay through the busiest periods of a day, namely rush hour. It will show how a MISTER system will be more than capable of catering for the entire public transport demands within any city, at a lesser cost than current public transit systems. As a comparison the London underground with a network of 400km of 2-way track is used and unlike the London underground MISTER will be profitable, generating a substantial income for a similar passenger carrying capacity and at a much lower investment cost, much quicker development time and with much better comfort and safety.

In 2007 London's underground carried over 1 billion passengers, approximately 3 million per day, with an average ride length of 10km at a cost of $5 per ride. The potential income should have been in excess of $5 billion yet it ran at a loss and required a subsidy paid for by the taxpayer. In the same circumstances MISTER would be profitable and deliver between 200 and 600 thousand 10km rides per hour which is approximately 3 to 7 million rides during a 12 hour period and comparable to the underground capacity. The peak time line capacity of MISTER is about 20% of that of the underground, but, with a greater network of lines would carry the same number of passengers during rush hours or at night, in greater comfort, faster and safer compared to the underground.

A cost comparison shows that the MISTER development and operating costs are between 20 and 50 times less than the subways and provide, for the same cost, an overall performance approximately 10 times better than subways.

Personal Rapid Transport (PRT) designs are currently under commercial development in several countries but to date none has been designed to have high passenger carrying capacity as MISTER. While all these competitive PRT systems feature supported vehicles, MISTER's cabins will travel suspended below an elevated and very light guideway infrastructure. The vehicles, called pods, will be propelled by electric motors powered by an external rail. This configuration will enable much easier implementation of parallel parking bays, the negotiation of steep grades, and have contactless rail switching at intersections and stops. The entire system will be fully controlled and automated by an autonomous yet distributed and intelligent, integrated computer network.

INTRODUCTION

The following analysis is applicable to PRT systems in general, however, certain assumptions and facilities apply to the MISTER design only for example all MISTER tracks (lines) are two way. It is also understood that no such analysis has been performed in relation to any other PRT system.

Fig 1 shows schematic topology of a city, served by a MISTER PRT system, with the following elements:

1. The Central Business District (CBD) of a 3x3 km area (grey box).
2. The CBD is divided into 750m-grid network of MISTER tracks, which total 30 km.
3. In addition, there are 20 external (spokes) tracks of 15 km each (not to scale), which are extending radially from the CBD to the “suburbs” (marked by broken blue line circles), therefore furthest stops will be approximately 16,5 km from the centre. Total length of radial tracks is 300km.
4. Solid red circle denotes a “ring track” of 3km radius, approximately 20 km circumference, which would connect to any points on suburban “spoke” lines bypassing CBD.
5. Broken red circle 7km from centre, denotes a second ring track, approximately 50km circumference, which provides additional connection between any points between suburban “spoke” lines bypassing CBD and shortening routes between suburbs**.**
6. Stadium (on the right of Fig.1) is served by 10 stops and is connected (blue lines) to 4 nearest main spoke tracks by 10km of special tracks.
7. Therefore a total length of two-way tracks is approximately 410km of primary lines (guideways), covering a “catchment area” of some 400km^2 (strip of 500m on both sides of the tracks).
8. Small stops, for 5 vehicles each, are marked by small circles (only within CBD). They are shown symbolically to reflect their high number. In reality they are placed more frequently than shown on the schematic, approximately every 333m (not 750m as on the schematics). There are 200 stops within the CBD with 2400 along all the lines of the whole system. Around the stadium area this does not apply, as there will be more stops (10) and with 10 vehicle bays each.

This model can be easily scaled and morphed onto a plan of any city with people and business concentrations along corridors and in various sub-centres. MISTER’s handling capacity will easily service such a varied configuration, therefore the validity of the analysis and its conclusions are not affected by a topology of any given city.

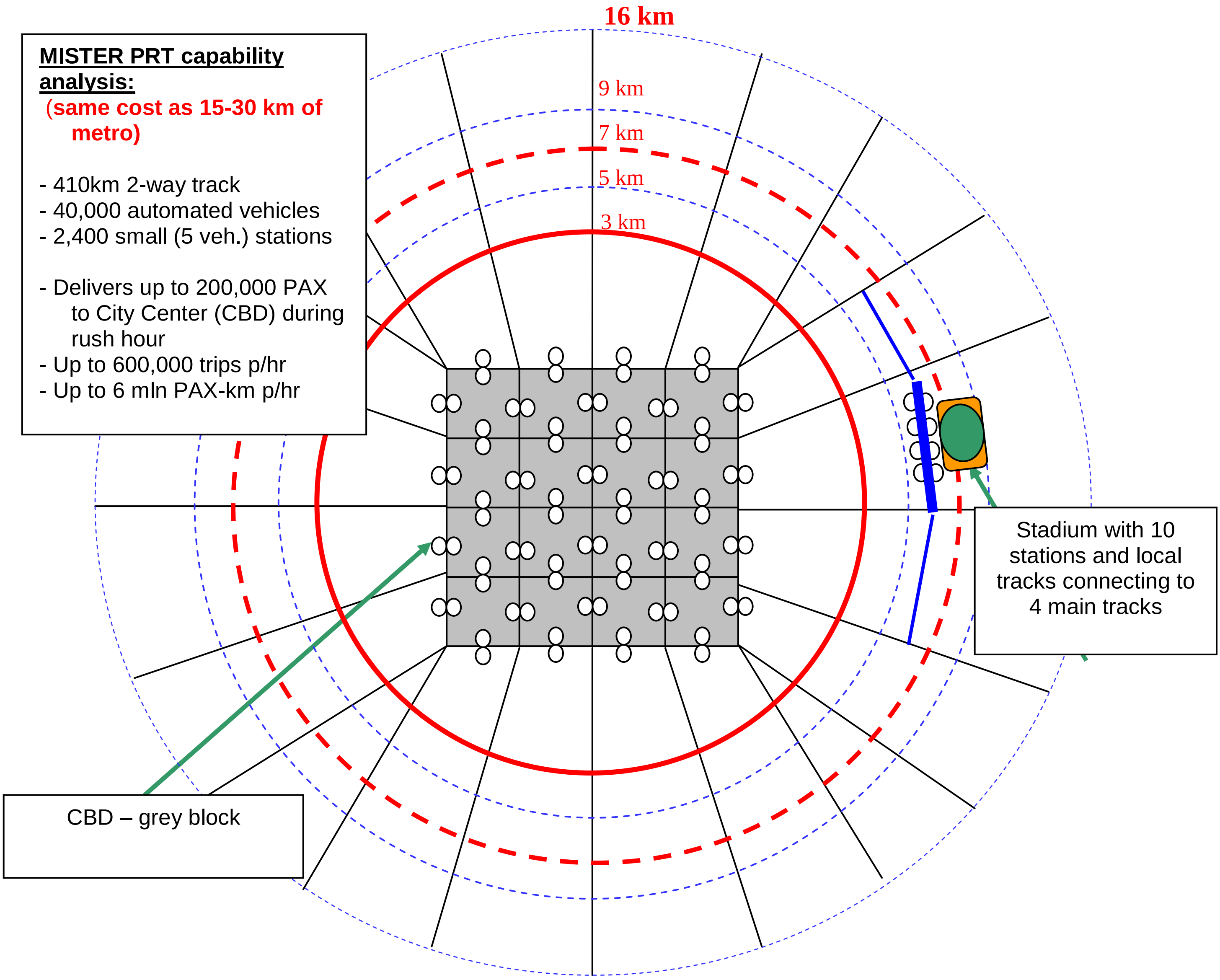

Fig 1 shows schematic topology of a MISTER PRT network within a city structure.

System capacity analysis:

An equal distribution of people across all areas would allow for a simple solution, but the system must cater for and is designed to cope with rush hour in the CBD.

By designing a system to address this situation will allow a lesser demand to handled by default.

Table1 shows the assumptions made and resulting calculations in relation to different average usage of the vehicles (shown in columns E-H).

An explanation and results are given below.

NOTE: MISTER is designed from “ground up” to meet the demanding requirements of the specified operating parameters, therefore less demanding parameters will pose no problem to the design team.

Each MISTER track consists of two unidirectional guideways suspended on the same column supports, with a maximum theoretical throughput of 5000 vehicles **per direction per hour** (**pdph**).

All vehicles are travelling at a constant speed of 50 km/h. This translates to 10m or 0,7 sec headway. This may appear to be small but very often these circumstances prevail to cars travelling in dense traffic. With the MISTER automation system the control of the 10m head way at 50 km/h removes human interaction resulting in more accurate and consistent operation providing greater safety compared to, for example, travelling in a car in city traffic.

(PRT is often criticised for not adhering to stopping times and other measures specified for trains. A MISTER pod when fully laden is half the weight half of the average car and can stop quicker in an emergency because they are not free rolling and employ "captive" braking. This is the same system used in an emergency by lifts, where they clamp to their guideway as a MISTER pod would do to its guideway and grind to a halt as quickly as is safe for passengers. Therefore railway standards cannot be applied to a system, where vehicles mass and dynamics are absolutely different and where reaction times are determined by a fully automated control system with an abundance of fail safe and safety mechanisms built in and can be considered to be superior to other transport system currently in operation.)

Assume a total number of vehicles within the system is limited to 50% of theoretical capacity, i.e. to 40.000.

Therefore of 5.000 pods **pdph**, on any section of the network, the actual number is 2.500 in motion in one direction per hour (average distance of 20m).

If and when local density increases to 100%, a pod every 10m, which could happen if pods group together, there will be a very short wait, a few seconds, before a pod will leave the stop and merge into the main traffic stream, without causing even a minor inconvenience to the passengers.

The spacing between empty pods is less than those with passengers permitting closer grouping when routing to other stops or to storage areas. As a result, there will be even more gaps on the lines during rush hours with fewer chances for congested stops and intersections. Outside rush hours, when many pods are idle and waiting at stops, gaps or congestion will not be an issue.

A study by Gothenburg PRT in 1990's reinforces the MISTER approach, and it is mentioned to demonstrate that the MISTER system can be more efficient than assumptions and calculations from that study indicate, because MISTER will have more vehicles thus reducing a need for their relocation and "empty runs".

The maximum travel distance from the furthest outer stop to the centre is 16km, which equates to a 20-minute ride, assume an average ride is 10km, which is the average on the London underground, and will take 13 minutes.

Only 50% of the fleet will be used to carry people towards the CBD in the morning rush hour, assume that the CBD is the destination for only 80% of commuters and the remaining 20% will pass through it without stopping therefore reducing the CBD delivery capacity of the system. As a result, only 2,000 vehicles per single line will stop in the CBD during rush hour, but with 20 lines converging on the CBD from the suburbs – it will result in 40,000 vehicles per hour going for the 3x3 km area of CBD.

The average occupancy for car traffic in cities in Western countries is 1.5 passengers. MISTER will provide individual travel mode, as a private car, therefore the expected passenger delivery capacity to the CBD during rush hour, will be **60,000. But it is likely that the average pod usage will be higher, as a result of incentives, for example a reduced ticket price when sharing a pod by 2 or more people. If the average is 2 passengers per pod, the system could then deliver 80,000 passengers to the CBD for each hour during the morning rush.** At the theoretical limit, of 5 passengers per Pod 200,000 passengers per hour could be delivered, this is comparable to a subway.

Most stops will have additional pod storage capacity, storage buffers located above the stops for 10 pods, therefore stops will accommodate all vehicles in the system when they are not in use.

Computer simulations made in Gothenburg in the 1990's, showed that empty pods would account for 27% of pods in motion. The MISTER system will have more pods per kilometre of network than these studies assumed, which reduces the need for empty runs, hence the 20% assumptions seems rational. **Even with a maximum ratio of empty to occupied pods during rush hours, i.e. 2500 vehicles per line incoming to the CBD and 2500 empty pods outgoing will not reduce the maximum line carrying capacity into the CBD calculated above.**

Passenger sharing to the CBD will be encouraged with incentives, for example, cheaper tickets to the same station, but not to intermediate stops. The model assumes most people travelling to the CBD in rush hour will head for the 3x3 km area; therefore it's possible that sharing will occur. If this is the case with at least 2 or more PAX per pod the maximum expected delivery capacity per line to the CBD during rush hour will be 2,000 pods times 2 PAX = 4,000 **ppdph (people per direction per hour). As there are 20 lines converging on the CBD, it follows that MISTER can deliver fast and in comfort a sustained volume of 60 to 80 thousand PAX per hour to the CBD from the suburban areas, even if the average trip length is 10km.**

It is anticipated that the general delivery capability of a MISTER system is a minimum of 2 to 6 million PAX-KILOMETERS per hour equating to between 200 to 600 thousand 10km trips per hour, equating to 3-7 million rides during a 12 hour period.

These estimates take into account reductions of available traffic due to the need for maximum capacity requirements at peak time, empty pods, passing through traffic and the partial utilisation of pods.

It can be seen that MISTER PRT can compete very successfully with subways and metros. In addition to the comfort, speed and safety benefits provided by MISTER it would be very profitable, unlike subways and metros, which require subsidies and also the cost of building a 30km metro network would build at the very least 400km of a MISTER network.

Stations capacity analysis:

Assume that each stop can accommodate **only 5 vehicles at any one time**. The length of a stop ramp will be 20m, similar to a single bus stop; including two 3m dead zones under the 45 degree ramps. It is a small footprint, shorter than most tram or bus stops, which are designed for 2-3 vehicles and are usually 25-50m in length. MISTER stops will not be more obtrusive or much bulkier than current bus and tram stops. They will be shorter, although wider, 7m. They do not have to be "off footways' or by the curb, as do bus stops and they can be placed inside buildings and on several levels. There small size makes it easier for them to be sited in more suitable locations bringing passengers closer to their intended destination, will make disembarking quicker and have a minimal ground footprint.

Assume that the average parking time for a MISTER pod is 30 seconds; this is conservative as most stop/start times for buses and trams is15 seconds, and for a subway 30 seconds especially during the rush hour. During this time, dozens of people, hundreds for subway, leave and enter these large vehicles. But for MISTER pods, they'll only be an average of 1,5 to 3 people who exit or enter, so 30 seconds can be considered conservative.

From above it can be calculated that each stop can receive and dispatch a pod every 6 seconds, therefore the hourly station throughput capacity will be 600 pods**.**

Adding 1 minute for each docking/start operation for each pod journey does not affect stop throughput calculations, it reduces transport delivery capacity to more conservative levels.

The number of PAX per pod will determine each stop PAX capacity to receive and dispatch. At 1,5 PAX per pod it will be 900 while at 5 it would be 3,000 PAX per hour.

In the model, there are 10 lines of two-way 3 km tracks within the CBD, giving a total of 60km of one-way lines. Stops are placed every 333 meters or less, hence there'll be at least 180 stops within the CBD.

Therefore a maximum total CBD stop absorption, throughput, capacity is between 160,000 PAX per hour and 400,000 PAX per hour, which reconfirms the previous calculations that small stops with 5 vehicles each will be able to receive and dispatch all of the passengers to and from the CBD and throughout the entire system. At an average pod occupancy of 1,5, to 3, the CBD and surrounding areas can receive 60,000 to 200,000 passengers per hour, which is one third the number that the stops can handle. So there will not be a bottleneck situation at stops, and the limiting factor of the system throughput is the number of lines.

As each MISTER line going through the CBD has 9 possible stops, and, realistically carrying 3,000 to 6,000 PAX per hour who disembark at these stops, demonstrates that average stop capacity in the CBD would only need to be 300 to 600 PAX per hour. MISTER stops have triple this capacity, therefore enough to cater for variations in the traffic demands. If required, more popular stops could be constructed to be twice as large as standard or stops could be spaced at 200m.

It can be seen that 3 stops with 5 parking bays each, could completely absorb the maximum line traffic, substantiating that stops are not a bottleneck in the system, and there are at least 200 stops along each bidirectional MISTER PRT line across the model city. Furthermore, MISTER stops have parallel parking bays, so, for example, a wheelchair bound or elderly person taking longer than expected to get in or out would not hold up other pods.

As previously mentioned the model would have 41,000 pods and 2400 stops with 5 pods, and another 10 pods on buffer lines above. Therefore stops are capable of storing all pods, when they are not in motion. To cater for all eventualities it is intended to have a further storage space for 10,000 pods available. These will be stored in so called "cage garages" and by introducing 100 of these, storing 100 pods in each, with 50 located in the CBD areas and 50 around the suburbs, will ensure that an excess of pods are near places of demand, suburbs in the morning and in city areas during the day and afternoon. These assumptions are made for the maximum system utilisation, which is not likely to happen from the outset of the system operation, however, it is important to understand all demands and implications of such a comprehensive system.

Sport Stadiums:

MISTER can deliver 30,000 people, 10,000 pods per hour to a stadium venue.

This is very demanding in terms of traffic and requires distortion to the symmetric city model, but can be achieved by a limited number of additional tracks connected to the nearest main "spoke" tracks serving general traffic.

As these venues will attract higher average usage it is expected that there will be 3 PAX per pod delivering on a single line 7,500 ppdph, from the 2,500 occupied pods arriving per hour, along each of 4 "spoke" lines heading from all parts of the city to the stadium.

Therefore a connection from these 4 separate "spoke" lines would provide a delivery capacity of 10,000 pods per hour with 30,000 PAX per hour, which would satisfy the venue's demands. Ten stops of 10 parking bays each would absorb12 thousand pods per hour, which is a more than possible line delivery capacity. So stops will not be a limiting factor in such a scenario.

On Fig.1, the first link to the nearest 2 main tracks, up and down, is drawn in a thick blue line, which denotes a 2 level MISTER structure. It is equivalent to 2 lines in each direction. These double lines will become a single line after the intersections with the first set of main “spoke” tracks, since half of the traffic will connect to these and the other half will carry on to the next set of “spoke” tracks, as shown.

If the stadium is located, for example, 7km from downtown, then the distance between the spokes of the suburban tracks is approximately 2,5km, therefore it’ll be necessary to provide between 8km and 10km of additional MISTER infrastructure.

These tracks will not be idle outside sporting events and will be utilised as shortcuts for any local traffic, thus improving system performance and connectivity in this area.

As these random sporting events occur usually on weekends, outside of rush hour traffic, additional pods will not be necessary to meet their transportation requirements.

Conclusions:

From the above it can be appreciated that MISTER can provide a superb public transportation system, superior to metro, bus and tram solutions but that cannot be compared exactly with metro capacities. Metro during rush hours has 6-10 people compressed into every square meter of floor space, whereas MISTER passengers are seated in air-conditioned luxurious comfortable chairs, and with 2 people on average per pod.

The assumptions are conservative and in reality there will be stops every 100m to 200m. It is anticipated that hotels, shops and offices will want MISTER stops as a way to increase patronage. As hotels provide taxis for patrons it is expected that MISTER will become the alternative transportation method, for example airport runs and to many other venues, as indeed will businesses avail themselves accordingly. In addition MISTER fares are comparable to a bus fare, which is a lot less than a taxi fare for a commensurate distance. A simple and inexpensive stop facility could have a major impact on a company’s bottom line. This could also contribute to stops being sited closer together than 300m, which will increase the system functionality providing greater benefit to the public and encouraging more people to use it.

If MISTER lines in the CBD are 300m to 500m apart, compared to 750m shown in the model, this will double their capacity, and increasing stop density will not cause any interference between lines as connecting guideways can branch out from each, reaching across to the sides of the main transit guideways. MISTER will also have the facility to carry two levels of tracks on its support columns, this also doubling the capacity of its lines, if and when required.

The MISTER system with its patented design of non-contact static switch enables expansion without any changes to the existing infrastructure. This is a major advantage as all extensions can built on an adhoc basis, as demand increases so the system can expand accordingly.

MISTER compares very well with any other public transport system, including metro, travelling time is half that of metro and between 2 and 4 times shorter than by bus or tram, especially in rush hours.

The cost for the MISTER infrastructure in its entirety is approximately 10-30 times cheaper than that of a metro system. The price of 400km two way MISTER tracks and 40 thousand pods, as indicated in the model, would only acquire 15km to 30km of a metro system, and MISTER operating costs are also lower, only 25-50% of that of metro or tramways.

In addition 400km of 2 way MISTER lines will deliver not only passengers across large parts of a city, but will also be able to carry most cargo deliveries and refuse in and out of the CBD and elsewhere.

Table1 : Summary of assumptions and calculations:

	params	calcs	Passengers (PAX)			
Lines capacities :			**MIN**	**expected**	**peak**	**MAX**
average PAX p/vehicle			1,5	2	3	**4**
2 way track length (km)	400					
max no. of vehicles p/direction-hr (pdph)	5000					
speed (km/h)	50					
vehicle separation (m)		10				
vehicle separation (sec)		0,72				
max no. of veh. p/km (two way)		200				
max system load factor pdph (% & v.count)	50%	2 500				
max no. of veh. In system		40 000				
Min no. Of empy veh. (% & no.)	20%	8 000				
system carrying capacity (veh & PAX)		32 000	48 000	64 000	96 000	**128 000**
average trip length & duration (km * min)	10	12,00				
trip duration with docking & start/stop (1 min)		13,00				
no. of avg vehicle trips p/hr (with dockings)		4,62				
avg. veh. speed with dockings (km/h)		46				
Rush hour capacities (one way):						
Rush hour CBD bound vehicles & PAX pdph	80%	2 000	3 000	4 000	6 000	**8 000**
Rush hour CBD bound capacity (lines & PAX/h)	20	**40 000**	**60 000**	**80 000**	**120 000**	**160 000**
MAX hourly capacities (two way):						
system rides capacity (veh & PAX trips/h)		**147 692**	**221 538**	**295 385**	**443 077**	**590 769**
system milage capacity (PAX-km/h)		**1 476 923**	**2 215 385**	**2 953 846**	**4 430 769**	**5 907 692**
stations capacities :						
No. Of stations (p/km and all)	6	2 400				
vehicles p/station	5					
stop/start duration per veh. (sec)	30					
in/out capacity p/hr (veh & PAX)		600	900	1 200	1 800	**2 400**
avg. station to line capacity ratio		0,3				
CBD stations p/line	6					
ratio of CBD line stations to total line capacity		**1,8**				
ratio of all CBD stations to all CBD lines capacity		**2,25**				
no. of CBD stations	180					
Average Rush Hour CBD station capacity req. PAX/h			333	444	667	**889**
CBD stations absorption capacity p/h			**162 000**	**216 000**	**324 000**	**432 000**

Comparison of transport systems "effectiveness"

This comparison does not account for the system features like comfort and operations economics. All current public transport systems must be subsidized, while MISTER will be not only self funding but highly profitable.

	Bus	LRT/Tram	Metro	MISTER
Length of network (km)	100	100	100	100
Total cost of a 1 km, 2-way track/road, with rolling stock (€ mil)	€ 10	€ 40	€ 150	€ 5
Average communication speed during peak times (km/hr)	10	15	30	50
Practical Maximum no. of passengers per vehicle in peak time	100	200	1000	2,5
Maximum no. of vehicles per 1 km of 2-way track	8	4	1	100
Maximum no. of passengers per 1 km of 2-way track	800	800	1000	250
Maximum Throughput per line (1 direction): Passengers per hour	4 000	6 000	15 000	6 250
Max. Network Transportation Capacity: Passenger-km per hour	800 000	1 200 000	3 000 000	1 250 000
Cost of network (€ mil)	€ 1 000	€ 4 000	€ 15 000	€ 500
Network effectiveness: Passenger-Km per € mil	800	300	200	2 500
Normalized (relative) Network effectiveness for the same cost	4,00	1,50	1,00	12,50
Normalized (relative) MISTER effectiveness vs. other systems	3,13	8,33	12,50	-