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Underground or aboveground? Making the choice for urban mass transit systems
A report by the International Tunnelling Association (ITA). Prepared by Working Group Number 13 (WG13). 'Direct and indirect advantages of underground structures'☆

ITA Working Group Number 13*

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Abstract

This report has been prepared by Working Group 13 (WG13) of the International Tunnelling Association (ITA). The question addressed in this report is how the decision is made as to whether to place Urban Mass Transit Systems above ground (either at surface or elevated) or underground. Following collection of a substantial amount of data from 30 cities in 19 countries, representing the situation from 1995 to 1998 (with some later updates), analysis of that data and deliberations on the issues raised has led to the findings and recommendations contained in this report. For many developing countries, the investment cost of a fixed guideway urban mass transit system is significant compared to the national or city economies. In order to assist future decisions, the report recommends that representative decision processes should be better documented and illustrated by reference to current and retrospective studies of typical projects, considering all costs and benefits, real and perceived.

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Contents

1. Executive summary

This report has been prepared by Working Group 13 (WG13) of the International Tunnelling Association (ITA). WG13's area of interest is the 'Direct and Indirect Advantages of Underground Structures'. The ITA maintains approximately 10 Working Groups at any one time studying various topics associated with the construction, maintenance and use of tunnels and underground structures.

Working Group 13 has, since 1989, studied the direct and indirect advantages of underground structures. Direct advantages are those that are specifically realized due to the placement of the structure underground and that fall within the mandate or prime function of the agency making the decision—in this case on underground vs. surface or elevated construction. Indirect advantages are benefits that are realized due to the construction of the underground facility but either are not specifically attributable to an underground location or else are not normally considered as relevant or quantifiable benefits by the decision-making agency or the community.

Urban mass transit systems range from buses operating on streets under normal traffic conditions that are capable, in major cities, of carrying up to 5000 passengers per hour in one direction (pphd) at average speeds of approximately 12–15 kph to fully-grade-separated Metro systems capable of carrying up to 60 000 passengers per hour in one direction at average speeds of up to 60 kph.

The question of how this decision is made-whether to place urban mass transit systems above ground (either at surface or elevated) or underground—is one that falls directly within the scope of Working Group 13. It has been found that the problems, and their solutions, regarding the question 'Underground or Aboveground?' are very different from country to country and from city to city and also there are many significant issues of concern to policy and political decision makers.

Following collection of a substantial amount of data from 30 cities in 19 countries, representing the situation from 1995 to 1998 (with some later updates) on the question 'Underground or above ground – making the choice for urban mass transit systems', analysis of that data and deliberations on the issues raised, the International Tunnelling Association offers the following findings and recommendations:

1.1. Findings

1. The decision on whether to place an urban mass transit system underground or aboveground is a complex planning, engineering, construction, urban design, economic and political decision.
2. In many cases—for example in the center areas of older cities—for functional, social, historic environmental and economic reasons there is no alternative to the choice of an underground alignment for new mass transit systems.
3. For many developing countries, the investment cost of a fixed guideway urban mass transit system is

significant compared to the national or city economies. For urban mass transit systems developed or operated by private companies, return on investment is a critical issue.
4. For newer cities, cities without extensive historical districts, and cities with wide streets, elevated alignments can offer full grade separation typically at substantially lower initial construction cost than underground alignments, with certain exceptions usually related to right-of-way costs.
5. The initial capital cost is only a part of the total long-term financial commitment. Costs include capital (including financing), operating, maintenance, security and rehabilitation.
6. Consideration of all costs—including capital, operating, maintenance, security and rehabilitation costs are necessary.
7. Consideration of all benefits—direct and indirect, short and long term—are necessary.
8. Long-term benefits such as increased economic activity and urban development potential are frequently not calculated in making the choice of whether to place an urban mass transit system underground or aboveground.
9. For the choice to be made well, both short and long term costs and short and long term benefits need to be objectively and comparatively considered.
10. Many aspects of the cost–benefit relationships are hard to quantify. Reference analyses and reports with the experience of other cities are very useful—particularly in the early stages of planning and design.
11. The problems of elevated alignments relate to availability of sufficient right-of-way, and the long-term environmental and real estate impact of elevated transit alignments. There are little quantitative data on which to base such decisions although there are many examples of older elevated railway alignments that have been removed due to public objections or to reverse urban blight.
12. In areas outside the city center, at-grade and elevated alignments offer the ability to construct greater lengths of transit system at the same initial capital cost or to lower the investment cost of a system of fixed size.
13. A cost ratio typically assumed for surface vs. elevated and vs. underground systems has been reported to be 1/3/6. Analysis of the data received from this questionnaire showed very large variations in cost ratios according to the particular circumstances of each city and existing infrastructure—which means that such ratios are not very useful in practice. The median ratios from the data received for this report were approximately 1/2/4.5.
14. Working Group discussions confirmed that (with some exceptions) the relative costs of underground systems relative to surface and elevated systems are tending to narrow. This is particularly true in areas of high land value and as environmental restrictions on surface and elevated construction monetarize the differences in land and environmental impact. Better technology and productivity for underground construction methods are also helping to narrow this cost differential.
15. Underground construction costs are tending to fall with time, as technologies and productivity improve. However, the costs of underground transit systems may not reflect this due to the fact that higher standards of amenity and safety are being built into new underground systems, e.g. large volume public spaces, air conditioning systems, better surface finishes, etc.

1.2. Recommendations

1. The choice of underground vs. aboveground for urban mass transit systems must be made by each city considering each area of the transit system, based on its own specific circumstances.
2. Few cities, which have had Metro systems in use for a substantial time regret the choice to build that system and, in general, to place it underground near and adjacent to the city center.
3. The above statement, and the economic/cost environment which supports it, should be documented and publicized to assist decision-makers in making choices for new Metro systems.
4. Cities and transit agencies that undertake specific studies of the relative advantages and disadvantages of underground transit alignments, especially those including long-term cost/benefit information, are encouraged to publish their analyses and findings for the benefit of other decision makers around the world.
5. The critical decision between an underground and an aboveground alignment in many cases is strongly, if not completely, influenced by the issue of perceived high initial capital cost. This decision should, however, consider the benefits of increased long-term social and environmental improvements and beneficial economic development.
6. Representative decisions for specific mass transit systems should be documented and illustrated by reference to current and retrospective studies of typical projects (including those older than 20 years), considering all costs and benefits, real and perceived. Estimates of changes in land value and perceptions in changes in environmental conditions close to alignments and, quantified estimates of all the benefits that have accrued to the region because of the particular project, would be of particular interest.

Examples of elevated vs. underground road alignments would also be pertinent.

2. Acknowledgements

The preparation of the questionnaire, the collection and analysis of the data and preparation of this report has extended over the terms of leadership of several individuals. Jean Paul Godard initiated the study as Animateur of the Working Group and continued to work for its completion as Tutor of the Working Group from the Executive Council. Subsequently, Ray Sterling, Animateur, with Christian Dochy and Pal Kocsonya, Vice Animateurs, led the Working Group during the collection of the data and the preparation of the initial draft report. Finally, John Reilly, Animateur, with Pal Kocsonya Vice Animateur, included additional data submitted by Working Group members, rationalized the findings and completed the report.

Special thanks must go to the individuals, listed following, who completed the questionnaires for each city. The work of Ms. Shanyun Wang, graduate student at Louisiana Tech University, who developed the spreadsheet tabulation of the questionnaire results, is also deeply appreciated.

3. Chapter 1 – Introduction

3.1. Background for the study

This report has been prepared by Working Group 13 on 'Direct and Indirect Advantages of Underground Structures' of the International Tunnelling Association (ITA). The ITA maintains approximately 10 Working Groups at any one time studying various topics associated with the construction, maintenance and use of tunnels and underground structures.

Working Group 13 of the International Tunnelling Association was formed in 1989 with the intention of better defining the direct and indirect advantages of underground structures. Direct advantages of underground structures are those that are specifically realized due to the placement of the structure underground and that fall within the mandate or prime function of the agency making the decision on underground vs. surface/elevated construction. Indirect advantages include other benefits that are realized due to the construction of the underground facility but either are not specifically attributable to an underground location or else are not normally considered as relevant or quantifiable benefits by the decision-making agency or the community. This

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UK	Newcastle	Ne	Paul Taylor, Tyne and Wear Passenger Transport, Newcastle
USA	Los Angeles	Lo	David Mieger, Los Angeles County Metro Transit Authority

(*) Abbreviation for the city used in this report is especially the case of some socio-economic benefits resulting from the realization of infrastructures.

For example, the time savings offered by an underground transit line over existing surface buses may be the same as the time savings offered by a grade-separated surface alignment. If, however, the surface alignment is not feasible and the underground is the only option, then such savings then can be considered indirect advantages of the underground transit system compared to the status quo. These issues were explored in a first report of the Working Group in 1995 (GCAAUUS, 1995; UCPICS, 1995). The Working Group then turned its attention to examining specific types of structures in turn. The first type of structure considered was underground parking and this report on urban mass transit systems represents the results of the second study. Also, of close relevance to this study, is an earlier report by the International Tunnelling Association titled '*Examples of Benefits of Underground Urban Public Transportation Systems*' (ITA, 1987).

The activities and publications of Working Group 4 '*Subsurface Planning'* and Working Group 15 '*Environmental Works and the Environment*' are also relevant to the issues surrounding the choice of underground or aboveground for urban mass transit systems.

3.2. Methodology

The Working Group based its report on the data received from an extensive questionnaire, developed by the Working Group and distributed to all ITA member countries. The questionnaire was designed to collect data about transit systems in each city, data about the economic and organizational conditions for the transit systems, and specific examples regarding the choices made among at grade, elevated and underground alignments. The major categories of data requested in the questionnaire are given in Appendix B.

Responses from 30 cities in 19 countries and 4 continents were received, representing the situation from 1995 to 1998 (with some later updates). Results were compiled in a series of computer spreadsheets, using Microsoft Excel, for documentation, analysis and communication. The results were discussed by the Working Group members at four annual meetings where the data were analyzed, report contributions made and, the findings and recommendations discussed.

3.3. Structure of this report

Following the introduction in this Chapter, the report begins first by providing a brief primer on urban mass transit systems in Section 5 and the issues surrounding the choice among at-grade, elevated and underground alignments in Section 6. These chapters provide background information and opinions on transit system issues, which are based on the experience of the Working Group members considering, but not necessarily drawn from, the questionnaire data.

Sections 7–9 provide data from the questionnaire responses on the 30 urban mass transit systems. Section 7 discusses the characteristics of the cities represented in the survey, Sectin 8 discusses the characteristics of public urban transport in the surveyed cities and, Section 9 discusses the financing, construction cost, and operation cost of mass transit on exclusive rights-of-way.

In Section 10, the issues of aboveground vs. underground for urban mass transit systems are discussed.

Section 11 provides conclusions and recommendations, respectively, from the Working Group study.

The data set obtained from the questionnaire responses contains far more detail than is presented in Sections 7–10. The spreadsheet summarizing the data contains many graphs comparing data among the cities and the data are mostly in English, with some descriptive materials in French. Because of the translations to English from many different languages, only minor editing was carried out on the descriptive responses in the workbook so as not to inadvertently change the respondent's meaning.

3.4. Comprehensiveness vs. rigor

For the reasons discussed at length in subsequent chapters, the decision on whether to place urban mass transit aboveground or underground is influenced by many factors, most of which are strongly influenced by the specific conditions of the particular region or urban environment. The major investment required for transit systems and the strong long-term impact on the economy and environment of the areas served mean that political decisions strongly influence the decision, need to be made—these, of course, are very specific to each region or urban environment at a particular time.

> Therefore, the Working Group notes that it is not possible, at present, to be both comprehensive and rigorous with regard to definitive conclusions in the analysis of costs and benefits of underground systems vs. aboveground systems and the specific factors that influence the decision 'Underground or Aboveground?'

This report, therefore, summarizes information from the questionnaire and the experience of the Working Group Members on those issues that are relevant to the question posed by this report ('Underground or Aboveground?'). The data collected reflect, in varying degrees, the context of the decisions made by these 30 specific cities decided regarding the question.

3.5. Glossary of terms

An extensive glossary of terms used by ITA is available at the ITA Website www.ita-aites.org.

Table 1
Objective, mass transit impact, mass transit requirements

Objective	Mass transit impact		Mass transit requirements
Socio-economic efficiency	1.	Passenger time savings	Must attract bus, auto or other mode passengers—requiring it to be rapid, relatively cheap and reliable.
	2.	Less traffic congestion	
	3.	Cost saving to society	
	4.	Facilitates commerce and growth of city	
	5.	Increases productivity	
Support for city development plan	6.	Allows urban areas to function more effectively	High passenger capacity per hour—increases transportation capacity between city centers and urban regions.
	7.	Can direct or influence urban development	
Social impacts and improvements	8.	Land acquisition and relocation during construction	Accessibility for most. This requires good pedestrian access (ramps/lifts)
	9.	Provides access for all (including elderly and disabled people etc.,)	Design for public safety must be satisfied
Environmental improvement	10.	Depends upon urban character, quality of Metro design, environmental laws and regulations	Identification of an alignment which contributes to the planned, holistic improvement of a corridor
	11.	Underground allows pedestrianisation and surface enhancements	Use of construction methods which mitigate adverse construction impacts
	12.	Reduction of surface impacts—e.g. noise, pollution, visual	Good design quality

4. Chapter 2 – The context for decision making for urban mass transit

Although modern telecommunications and internet use are facilitating personal and business interactions irrespective of the physical location of the parties involved, this does not seem to have stemmed the desire for travel. Intercity and international transportation continues to grow, as do the problems of congestion in major urban areas. In many urban areas, this congestion has grown substantially—in general much more than the population growth. The population explosion in developing countries, where growth is four times faster than in developed countries, has resulted in the creation of over populated ‘mega-cities’. Transportation, pollution and hygiene problems in these ‘mega-cities’ are very serious. Because of the growth in urbanization, economic development and requirements for increased mobility, cities all over the world face serious dilemmas concerning efficient public urban transportation.

Urban mass transit systems range from buses operating on streets under normal traffic conditions that are capable, in major cities, of carrying up to 5000 passengers per hour in one direction (pphd) at average speeds of approximately 12–15 kph to fully-grade-separated Metro systems capable of carrying up to 60 000 passengers per hour in one direction at average speeds of up to 60 kph.

The problems faced are very different from country to country and from city to city. There are many significant issues of concern that, in most cases, exist in all countries but the context of many issues is often specific to a country, region or city. This report attempts to illustrate some of these issues and to put them in context using the data obtained. Please note that the actual solutions to these issues can vary substantially from country to country, region to region and city to city.

4.1. Transit system choices

The objectives of mass transit systems, with examples of associated ‘Impacts and Requirements’, can be summarized as given in Table 1.

4.2. The requirements of mass transit systems

While it is difficult to generalize, the following points can be made:

For *developing* cities, the Metro needs to carry large passenger flows (of the order of 20 000+ passengers per hour per direction), reliably and rapidly along big radial corridors to the city center. Environmental aspects may previously have had relatively little impact upon the alignment decisions in some countries, due to the attitudes of decision-makers in those times, but this is changing quickly—particularly as environmental sensitivities are progressively raised.

In many *developed* cities with significant population growth, where a Metro has previously been constructed to carry passenger flows reliably and rapidly along the big radial routes to the city center, planners are considering addition of orbital (circumferential) systems to meet transportation needs from suburbs to suburbs. The

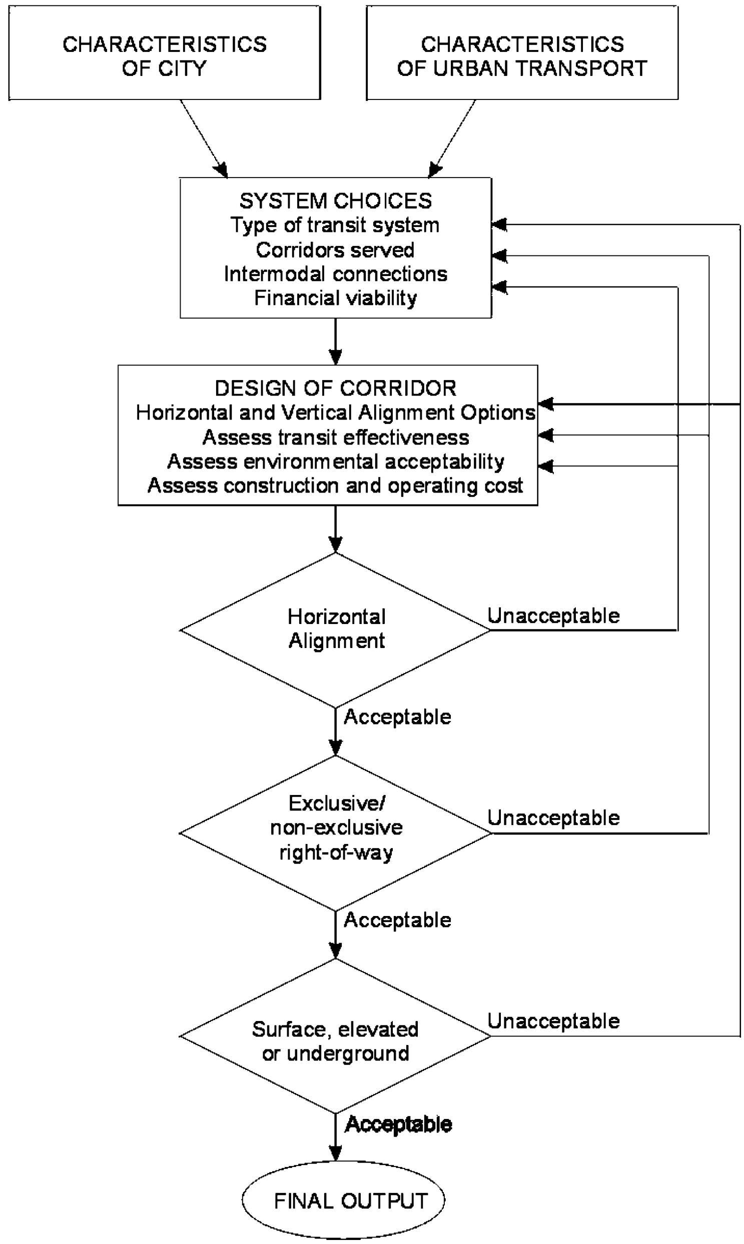

Fig. 1. Decision diagram, urban mass transit systems, aboveground or underground.

main objective of the introduction of orbital systems is to meet transportation needs from suburbs to suburbs, which are currently-dependent upon the use of private cars, buses or, if available, a routing through the city center using the radial transit lines.

The importance of speed is very significant. It is the major key characteristic that brings a significant economic benefit to the region through reduction of travel time for a large number of people.

4.3. Meeting these requirements

A new transit system introduces an additional choice of transportation mode for the urban population. While this has positive impacts for urban mobility, a key challenge for all systems is to attract riders. A new mass transit system does not automatically have a guaranteed patronage—many potential passengers, with the exception of persons who rely only on public transportation, will have an alternative mode of transport available and will need to be 'won' to the transit system. This requires that competitive fares, reliability and speed of operation be given high consideration.

Funding is always a problem—where subsidies are not available, the pressure for modest (competitive) fares requires low capital, operating and maintenance costs. It is, therefore, a requirement to balance the desire for a system that has high functionality and low environmental impact with the need to identify a system that is both low-cost (i.e. within available funding) and rapid in operation.

Often, without government intervention and support, these choices are made on the short-term needs of the transit system with little consideration of long-term social policy, planning implications and comprehensive long-term benefits of the transit system. While the initial differences in costs between different types of transit systems and their vertical alignment (at grade, elevated or underground) may be very significant, the increased initial capital costs for underground systems should be considered a major part of an investment in the transportation network for the city—resulting in the long-term benefits and increase in social well-being and economy that derive from an effective, rapid transit alternative to automobiles with more positive environmental benefits. A 'Return on Long-term Investment' approach has great merit and should be considered more often.

High-speed Metro operations require grade separation from other traffic. There are three generic levels of separation:

1. *Complete separation* ('exclusive right of way') – allowing operating speeds (including stops) to be typically 30–60 kph, the figure depending primarily on station spacing. This generally leads to fully elevated or underground solutions.
2. *Substantial separation* – meaning horizontal protection from other road traffic, and priority over other traffic at road junctions. The operating speed is typically 20–30 kph.
3. *Partial or no separation* – meaning that other traffic uses the same road as the transit system, and transit priority at intersections may or may not be provided. Typical operating speeds are 12–15 kph.

Transit systems that are successful (because they may have high demand, low fares, high speeds—or a combination of these) need a capacity commensurate with patronage. High speed, and, therefore, high capacity, requires complete grade separation from other transport systems.

Finally, fully separated systems can be automated. Thus, we have the generic mass transit technologies as follows (the classifications are those proposed in the Questionnaire):

1. *Completely separated systems* (e.g. Metros, Urban Rail and Automatic systems) – achieve high speeds in operation because they are fully separated. They usually attract a 'mass' ridership with a high passenger per hour capacity.
2. *Partially separated systems* (e.g. Light-Rail Systems, Modern Tramways) tend to have a lower initial capital cost than completely separated systems but also a lower operating speed—because of this, they have a lower capacity and may attract fewer riders.
3. *Non-grade-separated systems* (e.g. Tramways, Trolley systems) have lower initial capital cost but are relatively slow—thus they have the lowest transit capacity.

Bus Rapid Transit – roads for the sole use of buses, usually in the center of highways, sometimes on new alignments—could be added to this list of technologies since they are conceptually similar. However, they remain relatively few in number, although there are several in South America, the United States, Canada, Australia and France (Fig. 1).

5. Chapter 3 – Implications of vertical alignment and associated construction options

5.1. Introduction

Vertical alignment has a very significant effect on initial capital cost and the surrounding environment, but a smaller effect on choice of technology for mass transit systems and recurrent costs. The effect of vertical alignment on patronage and revenues depends upon greatly varying circumstances. Because of the large investment required (capital and recurring costs) and the significant urban and environmental impacts, the choice is nearly always resolved politically.

A fully separated, underground alignment with substantial freedom from surface factors (roads, buildings, etc.) should theoretically have 'free choice of route' – but this is frequently not the case. Thus, the apparent routing freedom that an underground alignment could provide is surprisingly seldom realized in practice. Instead, mass transit systems tend to follow the same corridors (usually roads) that elevated systems would logically follow. The reason is probably that following these corridors offers a better solution to the location of, and access to, stations and, therefore, riders, as well as lower right-of-way costs and impacts on adjacent structures.

Because budgets are almost always constrained, and underground Metros normally incur large initial (capital) costs, the alignment decision always involves more than technical issues. For example, for resource-constrained cities, the choice may be:

1. Build an at-grade or elevated alignment (now), or
2. Wait to build an underground alignment later—when funding may be available.

Once built, mass transit systems become an integrated part of the urban fabric and are very difficult to relocate. Thus, decision-makers often face a difficult choice: whether to provide an elevated, but initially lower cost, system now—and live with the generally adverse environmental consequences—or defer construction until an underground alignment becomes affordable (recognizing that environmental perceptions may well strengthen in the future as incomes increase). The decision to build an elevated structure initially has several long-term implications:

1. It limits options for future transit or highway facilities—forcing them either to transition over large vertical distances from elevated to grade or underground or forcing multi-level elevated interchanges that further degrade the surface environment.
2. The actual cost to relocate a line underground at a later date is usually much more expensive than the current difference in costs—because of the need to preserve the current line in operation during the new construction and change over and then demolish the elevated line and restore the environment.
3. The social and real estate implications of neighborhood severance and environmental impact of an elevated structure are difficult to quantify but tend to increase with time as the elevated structure ages.

In practice, the specific characteristics of the corridor—in terms of urban design, existing right-of-way, geology/ground conditions and financial/social/political circumstances—particularly affordability and environmental perceptions—determine the balance of advantage between at-grade, elevated and underground construction for each section of the route. It follows that a route may be underground in sensitive areas and elevated (or at-grade[1]) elsewhere.

The 'alignment' issue is usually of central importance to mass transit, and hence to the transport strategy of the city. This reinforces the critical need for sound, objective, comprehensive and rigorous assessment of the alignment options. However, depending on the country, this kind of detailed study is not always carried out and, in fact, is difficult to achieve. In many studies, the real but hard-to-quantify long-term costs and indirect benefits are discounted in favor of the more easily quantified initial costs and short-term benefits—providing apparent 'rigor' in the quantifiable areas evaluated but losing comprehensiveness in terms of balancing easily quantifiable impacts against urban design and environmental issues over the lifetime of the system. This is a major area of focus to improve the quality of decision making for such systems.

5.2. Impacts of vertical alignment choice

The impacts directly related to choice of vertical alignment may be classified as follows:

- Capital cost
- Visual/aesthetic
- Ridership
- Dividing the community
- Development potential
- Construction impacts
- Difficulty obtaining right-of-way
- Vibration
- Operating cost
- Air pollution
- Noise
- Risk to cost, schedule or quality

5.2.1. Capital cost – ratios for at-grade, elevated and underground systems

The first issue to note is the large initial capital cost of Metros, usually measured in US$ billions. Indeed, a Metro is often the largest investment a city will ever make. A review of mass transit projects worldwide concluded that, based on available data[2] the 'all-in' cost of fully segregated Metros in Asia is about:

Type of construction	US $million per route kilometer	US $billion (15 km line)
At-grade	30	0.5
Elevated	75	1.1
Underground	180	2.7

The above figures show typical, but not universal results. A 'rule-of-thumb' for ratios for the initial cost of segregated transit systems has been quoted[3] as:

Construction	Cost ratio
At-grade	1 (base)
Elevated	3
Underground	6

However, the data collected for this report show very wide ranges of costs in various systems with median ratios across the systems reported of:

Construction	Cost ratio
At-grade	1 (base)
Elevated	2
Underground	4.5

It is noted that the cost of tunnelling has been declining, due to better technologies and productivity which is consistent with the above tables. This would indicate that as underground construction becomes more competitive, more consideration should be given to

[1] At-grade alignments are however rarely feasible in major cities.

[2] Data on cost of Metros in developing and developed countries—see Allport and Bamford (1998).

[3] Different ratios have been quoted in different geographic locations—this set is thought to be representative.

underground systems which are more environmentally and socially beneficial.

Also, there are cases where, when relevant factors were included, the initial capital cost of an underground system was the cheapest, elevated next and surface most expensive. For example, in the case of the Los Angeles Metro, San Fernando Valley extension, the alignment was along a freeway and the total costs were strongly influenced by the cost of displacing neighboring houses and the need to purchase expensive right-of-way (Reilly, 1996). The survey data does make it clear that the choice of vertical alignment is almost always the most important factor influencing initial project cost and financing decisions.

5.2.2. Visual/aesthetic

The visual/aesthetic impact is often the major quoted reason for deciding to locate transit underground instead of at-grade or elevated. It would seem self-evident that elevated structures impact strongly on the visual image and character of a corridor—something that an underground system does not. Whether this impact is good or not depends significantly on the quality of design, the characteristics of the corridor and the perceptions of the residents. It also depends on how the appearance of the structure is maintained over time. A major factor in Metro planning involves determining how and whether the transit system will add to—or detract from—the urban environment.

Two examples are given:

1. In Singapore, the government decided internally, before a feasibility study that had been designed to evaluate the options was completed, that the North-East Sector Line should be underground through central Singapore. This decision was not taken lightly (a significant cost penalty was involved) in a state where most of the MRT system is elevated.
2. In Bangkok, the Seventh National Plan incorporated 3 Mass Rapid Transit (MRT) systems and 4 Expressways, for which the Cabinet had approved concession agreements. All were elevated. There was considerable doubt about their physical feasibility and some concern about their environmental impact in low-lying Bangkok, which has often been referred to as the Venice-of-the-East.

In the first half of the 1990s the impact of the planned concrete 'spaghetti' was realized—leading to a Cabinet decision that, in the 25 km^2 city center, all projects should be underground. Two of the Expressways and two MRT systems, all under construction, were exempted from this ruling (it was accepted that these expressways should not be underground); but the third government MRT system has been developed on a fully underground alignment—as will be all future systems.

Interestingly, social surveys in Bangkok have established the population's concerns about environmental issues. The No. 1 problem by far is air pollution, while the No. 2 problem, for those with poor water, is the water supply. All other problems are perceived as much less important. An explanation of the differences between the government decision and the people's perception is that major urban infrastructure once built is extremely difficult and expensive to change. Air pollution and water supply are difficult urban problems that require ongoing measures but do not define the physical character of the city for the foreseeable future.

5.2.3. Ridership

In most urban areas, including city centers with complex street structures, it is generally not acceptable to create a new elevated alignment and, for social reasons, an underground alignment is considered 'essential' where a Metro must traverse the heart of the city center. Therefore, if an underground alignment which is not constrained to follow the existing road network is compared to an elevated alignment that must follow the existing road network, the underground alignment could allow a Metro to serve traffic demands better and hence there may be a positive impact on ridership—including higher numbers of patrons, reduced travel-time and better convenience because journeys can be more direct and may require less interchanges. Experience, however, suggests that the unconstrained alignment choice occurs less often than might be expected.

This major potential benefit—the freedom of underground alignments—is infrequently realized in practice. This can be due to a combination of underground construction cost and risk, legal difficulties and project delays due to easement acquisition, and perhaps constrained thinking on the part of transport planners and a lack of appreciation of such issues by politicians.

By contrast, in cities, particularly planned grid cities that have developed on the basis of wide arterial roads with sufficient median, the underground alignment may offer little ridership advantage over an elevated alternative. However, social, aesthetic and environmental considerations are strong factors that generally favor underground systems in urban cores.

There are further ridership issues:

1. Underground stations may reduce ridership if the station is at great depth underground, by causing certain passengers to prefer surface modes.
2. Real or perceived passenger safety may be an issue. In some cities, (e.g. Birmingham in the UK) a significant number of patrons, particularly women, stated that they would resist traveling underground for security reasons. In other cities (e.g. Vienna) the underground transit system is considered a safer and

more pleasant mode of travel than surface transit options.

Where underground and elevated alignments co-exist, interchanges can be very difficult. Once an elevated alignment has been constructed, future elevated crossing lines must result in two-level elevated structures or there must be substantial vertical interchange arrangements to connect to an underground line. The interchange between two underground lines is less problematic.

5.2.4. Dividing the community

An at-grade and, to a lesser extent, an elevated transit system, can significantly impact a community by dividing residences, businesses, amenities and utility corridors. Negative impacts can result from the combination of a constrained corridor, chronic traffic congestion and land ownership patterns that constrain property redevelopment. The result can be a degradation of the physical environment, with passage across the transit corridor permitted perhaps only at intervals along the right-of-way or at stations. This can also cause businesses or residents to relocate, perhaps 'down-market', with the mass transit system creating a physical barrier to movement of people and vehicles between communities on either side, with economic impacts to the adjacent communities.

Elevated structures in the wrong corridor or location can create physical as well as visual separation—and may blight frontage properties. For example, the proposed Hopewell project in Bangkok would have built an integrated development structure right through the city on both its major axes, following the rail lines. This was abandoned, but clearly, it would have created significant separation since it was three levels high and it was not possible for other infrastructures to cross it.

5.2.5. Development potential

Well-planned underground alignments allow more effective integration of the Metro with property developments adjacent and over stations. This maximizes the prospects of intensification of land use where accessibility is at its highest and it offers the prospect of development gain—which may also assist in funding the Metro. These potential benefits depend upon effective planning to be realized in practice: where this exists, such benefits may be substantial and the resultant benefits can be very important. Experience suggests this is likely to happen where government and the planning system are effective.

5.2.6. Construction impacts

Traffic disruption from cut-and-cover construction is a very important issue. At one extreme, for example in Hong Kong, experience of disruption during cut-and-cover construction along Nathan Road (for the MTR Initial System) led to a decision to exclude cut-and-cover methods from future consideration. But this is not a simple 'black-and-white' issue—it is influenced by existing construction practices and cost issues—including the cost of economic disruption during the construction.

1. Most disruptive of construction methods is cut-and-cover construction, which is often used for underground stations and sometimes for the line structures which connect the stations.
2. Significantly less disruption is caused by elevated construction since construction is primarily at the column locations—however, station structures have a significant impact during construction (and the final structure has long-term visual and noise impact).
3. The least disruptive method is tunnelling for line structures and mined techniques for stations. The only impacts are at portals, access shafts or entrances where significant space may be is needed during construction. Mined stations may have more demanding construction requirements than conventional cut-and-cover construction resulting in a minor cost increase—although when the costs of economic disruption to adjacent business are considered, cost may be reduced overall.

5.2.7. Difficulty obtaining right-of-way

A potential Metro alignment often faces three right-of-way problems—one physical in relocating buildings and activities and avoiding other infrastructure, the second is associated with legal and land acquisition costs and the third is political related to resistance to real estate acquisition. Additionally, there will be opposition to any reduction in surface or road space (for elevated and surface Metros) and all citizens are concerned regarding or impact to adjacent properties.

Politically, right-of-way acquisitions can be unpalatable and, therefore, following the route of an existing road (which usually requires a much reduced right-of-way taking) may provide the most attractive political alignment for a Metro system.

5.2.8. Vibration

Vibration can be a significant issue in the case of underground alignments, particularly where the alignment is under a historic center with important, old buildings or is located near sensitive facilities such as hospitals, research centers or universities. Measures to reduce vibration to acceptable levels are available, at some incremental cost (usually small).

5.2.9. Operating costs

Ventilation, lighting and staffing requirements are factors that increase operating costs for underground systems. Air conditioning of underground stations also is a significant factor in tropical environments. Platform-screen doors can mitigate this but they also add cost—

although this cost does provide increased customer comfort and particularly safety.

5.2.10. Air pollution

This is an occasional problem—at its worst when elevated stations over a congested road create a 'tunnel effect' in heavily trafficked constrained corridors (for example, the Silom Road section of the Bangkok Green Line). For underground alignments, the main issue is the location/design of ventilation shafts to avoid undue localized pollution.

5.2.11. Noise

The noise associated with elevated structures in urban environments is problematic even though advances in noise reduction for wheel/rail and vehicles have reduced this impact. Surface rights-of-way have similar noise issues. Underground alignments are the quietest of all, especially when track isolation measures are used.

5.2.12. Risk in terms of cost, schedule, quality

The impact of possible risk events on cost, schedule and quality can be significant. The impact of these risks are generally accepted to be higher for underground structures—although risk is a significant factor for all infrastructure construction in dense, urban areas. Metros have a justified reputation for exceeding their first cost estimates by significant margins—most particularly where underground construction is required. Cash-strapped governments and Build-Own-Transfer (BOT) concessionaires, requiring a definite return on investment, are, therefore, naturally cautious about underground construction because of its inherent uncertainty and the time required for construction. On the other hand, surface and elevated alignments may also suffer long delays due to public objections to the proposed design due to environmental reasons.

The effects of not considering risk in the planning, design and management of transit projects is significant—as demonstrated by those projects which have lost public support when 'unexpected' conditions occurred, causing increased costs, longer completion schedules and construction or other impacts to adjacent properties. However, it is noted that there are many projects, which have been successfully completed close to their budgets and schedules.

Recently, systems to better quantify risk and its probable impact on projects have been introduced. These include the Decision Aids in Tunnelling (Einstein et al.) and the 'Cost Estimate Validation Process' for infrastructure projects (Reilly et al., 2002).

5.3. Key issues which influence horizontal and vertical alignment decisions

The key issues that influence horizontal and vertical alignment are:

1. The state of public finances—that is, the availability of funding which determines what can be constructed and the quality (level of facility) to be provided.
2. Governmental policies related to the choice of horizontal and vertical alignment—including effect on adjacent facilities. This includes social factors in the planning and development of such alignments.
3. The procurement system, specifically the trend to private sector participation.
4. Environmental regulations and,
5. Other miscellaneous factors.

5.3.1. The state of public finances

Underground Metros have large initial capital costs. The government is often not willing or able to fund such projects from public finances and the private sector, by itself, cannot remedy this problem, for example by Build-Own-Operate-Transfer (BOOT) projects, (because it is almost impossible to make Metro systems pay for themselves from fare box receipts). Most Metro projects will require most of their initial cost to be funded by government—whether or not the private sector implements/operates them under a concession.

Faced with resistance to increasing taxation and global pressures for international competition, many governments are targeting expenditure only to 'core imperatives'. Examples include Europe and the United States, where monetary and political policies are forcing cuts in public expenditure in countries that have hitherto invested substantially in infrastructure. Generally, it is difficult to see that this trend will reverse in the near future. This leaves the question as to what is a 'core imperative' for a country or a city and whether mobility for all sectors of the population, together with environmental preservation, is a key political or public concern.

5.3.2. Governmental policies

In general, complex infrastructure projects require effective planning, management, design, procurement and construction. If this is not the case, it is probable that significant problems will arise. Government has an essential role and responsibility in the successful execution of these projects. Therefore, it must:

1. Identify the project, which it must then strongly support through implementation and operations.
2. Obtain the necessary permissions (from local authorities, environmental agencies, etc.).
3. Manage the process of public consultation, particularly where relocation and environmental issues arise, and then manage public information through the construction process.
4. Ensure that regulatory bodies control construction impacts, and that traffic diversions are well managed through the construction process.
5. Ensure that the project is effectively integrated with the remainder of the transport network.

6. Provide finance for the project as agreed and set fares at acceptable levels.
7. Ensure good management of the project and communication with 'stakeholders'.
8. Ensure good quality operations provide clean, safe, efficient and effective public space and provide effective maintenance throughout the entire service period.

This role is considered more demanding for underground construction. Where governments are not sufficiently effective, then underground construction may be at a disadvantage—meaning that the program cost and schedule may be subject to increases due to ineffective management.

5.3.3. Procurement system – private sector participation

Increasingly there has been a trend towards private sector participation, in which risks are transferred to the private sector, in return for appropriate financial compensation. In the future this trend is likely to continue. In some cases, there has been talk of full BOOT projects with a very large risk transfer, but this has been problematic. A guiding principle is that risks must be managed by the party best able to control them.

The general experience of private sector involvement is that the companies involved must have a clear focus on feasibility, implementability, fundability and risk control. This often translates to a preference for elevated construction:

1. Where government is not effective, elevated systems may be seen as a lower risk alternative.
2. Local contractors may be more experienced in elevated construction than tunnelling which requires more specialized skills
3. Elevated construction is usually a lower initial capital cost, increasing the project's fundability.
4. The construction risks (geotechnical, etc.) associated with underground construction are greater than those for elevated structures.

If government is strong and capable, it is better positioned to undertake a wider range of feasibility studies and be more strongly involved in a long-range development and implementation strategy. In this case, the government is in a better position to make a more rational decision—based upon of the merits of differing alignments and considering long-term costs and benefits. But in many cities, government is not sufficiently strong or, alternatively it may take a 'hands-off' attitude towards new infrastructure, believing that the private sector should be the catalyst in identifying projects. In this case, it is likely that mass transit projects will be mainly elevated.

5.3.4. Environmental regulations and public perceptions

The environmental regulations of the country and the requirements of funding agencies are very important factors. Most countries—developed and developing—now have Environmental Assessment and/or Environmental Management Plan requirements in law and these are being increasingly applied in practice.

Environmental compliance must be demonstrated in project development, design, construction and operations. Thus, it is often necessary to produce an Environmental Statement, an Environmental Mitigation Plan, an Environmental Monitoring Plan and/or an Environmental Management Plan for the construction period.

Environmental perceptions and architectural preferences are not necessarily transferable from one country to another and these perceptions may change over time. People tend to put increasing value on their environment as their incomes rise and, as incomes are expected to rise in most cities contemplating mass transit systems, a trend towards good-design and less-intrusive, underground construction is expected. It is government's role to create a regulatory and investment framework that results in the right blend of environmental/aesthetic and performance/cost/risk acceptability—both for current conditions and also future city development needs.

5.3.5. Other miscellaneous factors

It is not uncommon to find that other factors have a large influence on the alignment and grade decision. Some of these factors include:

1. Security—underground stations can be designed as shelters in time of emergency. In some cases, this has been a factor in the choice of alignment.
2. There is often a belief that 'Metros' must be underground. Many cities (e.g. Shanghai, Tokyo) have mostly elevated expressways (which are much more environmentally intrusive) and mostly underground Metro systems.
3. Simple decisions (aboveground or underground?) often seem to be preferred—rather than to recognize that there is a balance of advantage, which may change between the city center and the suburban radial corridors.

6. Chapter 4 – Key characteristics of the surveyed cities

6.1. Cities that responded to the questionnaire

Thirty cities from 19 countries and 4 continents responded to the survey distributed by the Working Group. The cities are very diverse in terms of their physical and cultural setting, economy and historical development patterns. The cities are listed in the introduction to this report, with the names of the persons who contributed the data. The tables in this report (following) present summaries and comparisons, by city, of the key data characteristics. The cities are listed in the order of Region, Country and City (Table 2).

Table 2
Cities responding with city abbreviations

Country	City	Abb.
Japan	Nagoya	Na
	Sendai	Se
	Tokyo	To
Rep. China	Taipei	Ta
Singapore	Singapore	Si
Belgium	Brussels	Br
Czech Republic	Prague	Pr
France	Rouen	Rou
	Lille	Li
	Lyon	Ly
	Paris	Pa
	Rennes	Re
	Toulouse	To
	Strasbourg	St
Germany	Hamburg	Ha
Hungary	Budapest	Bu
Italy	Milan	Mi
	Rome	Ro
Netherlands	Amsterdam	Am
Norway	Oslo	Os
Portugal	Lisbon	Ls
	Porto	Po
Romania	Bucharest	Bc
Spain	Barcelona	Ba
UK	Newcastle	Ne
Russia	Moscow	Mo
	St. Petersburg	SP
USA	Los Angeles	Lo
Mexico	Mexico	Mx
Brazil	São Paulo	Sa

This discussion will only highlight selected elements of the data provided by the survey in order to give a background for the discussion on choices for underground vs. aboveground transit made in each city.

6.2. Geography

The center city area of cities responding varied from only 35 km^2 for Rennes in France to over 1500 km^2 for Rome and Sao Paulo. The size of the urban areas containing underground mass transit varied from 285 to 8600 km^2. The population of the center city varied from 105 000 in Rouen to 9 650 000 in Sao Paulo and the population of the conurbation from 332 000 in Rennes to 29 570 000 in the Tokyo-Yokohama area. The population density of the city center varied from 2250 persons per km^2 in Hamburg to 30 000 persons per km^2 in Barcelona. The average population density of the cities responding is 10 430 and the median density is 8400.

A commonly used rule-of-thumb for transit has been that a fixed rail mass transit system becomes viable with city populations of over 1 million people. While this is true of most of the cities responding, 6 European cities responding to the survey have populations of less than 1 million—Rennes, Rouen, Strasbourg and Toulouse in France plus Prague and Oslo. The use of underground mass transit in the smaller French cities has been made possible by the use of small-scale, highly automated lines that are designed for these conditions. Normally, for smaller cities, there needs to be a strong political and social imperative or specific historical or geographic reasons for a fixed rail mass transit system to be considered and implemented.

Charts in Fig. 2 show the key characteristics of the urban areas from the data received.

6.3. Geology

Favorable geological conditions are rarely a determinant in deciding to build an underground mass transit system. Geological conditions, however, do strongly affect the cost of building an underground system and can strongly influence decisions about how much of the route length to place underground. Many major cities of the world are sited on river estuaries and hence have soft or loose deposits of saturated clays, silts and sands. However, it is also true that many cities are founded on rock—many of the cities responding to the survey had rock present in the zones through which the underground transit alignments pass. The construction of all transit systems has to accommodate ground conditions that are variable and poorly understood prior to construction. This latter fact accounts for many of the significant cost increases encountered during the construction of underground systems.

All the cities responding to the survey had groundwater present in the zones used for mass transit construction. The minimum groundwater depth reported was 1 m and the maximum 25 m. The median depth to groundwater from the responses was 5 m—although, of course, the depth to groundwater varies over a large range for each individual city.

6.4. Economy

Since underground mass transit systems are expensive to construct, it would be expected that such systems would be built in cities and countries that have sufficient economic ability to afford the cost. Data on questions about the city and country economy were only provided by some of the responders to the survey.

There are a number of relatively poor countries (in terms of GNP/GDP) that have cities with underground transit systems. In these cases, these cities tend to be the economic, political, historical and/or cultural heart of the country. For example, in Hungary, Budapest provides a substantial part of the country's GDP.

In countries with larger economies and high urban densities, transit systems extend to cities with much smaller roles in the national economy, e.g. Nagoya that provides only 2% of the GNP in Japan. The data on

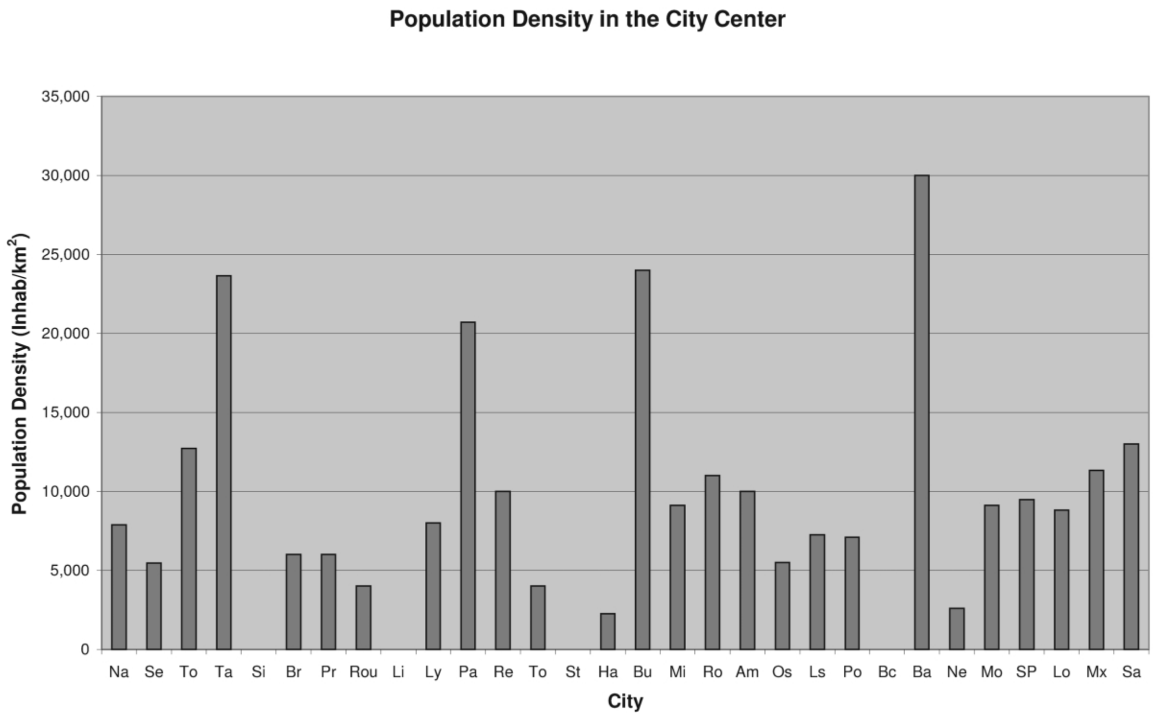

Fig. 2. Population density in the city center.

GNP per city inhabitant show a wide range from US$3610 per person per year in Mexico City to over US$60 000 in Tokyo—both cities have heavy underground Metro Systems. This confirms that there are other imperatives that drive the choice of a mass transit system besides income.

6.5. Urban fabric

The existing city layout and road density affect many aspects of transportation planning. The responses to the survey describe the overall layout of the city and the proportion of the city area provided in street networks. These data can be misleading in cases where large parks and other open spaces are within or close to the city center since overall densities may not be representative of the congested conditions within the city area itself.

The responses do not cover the full range of street network conditions since no data on street area were provided for several cities. However, two groups of cities can be seen in the data—cities with historically narrow streets that have maintained this street network and pattern (e.g. Sendai, Taipei, Budapest) and cities that have carried out a significant widening of streets and city redesign at point(s) in its history (e.g. Paris, Mexico City, Brussels, Oslo). The former cities have extremely low percentages of area in streets (2–7%) whereas the latter may have street areas up to 25% despite high urban population densities.

6.6. Heritage

Almost all the responding cities have to deal with historical districts, archaeological and cultural landmarks, and/or areas of environmental protection. All but two of the cities responding indicated that there was special legislation for the protection of such landmarks and areas. Such districts and landmarks may encourage the use of an underground alignment in that area but this can also raise the cost of construction of the system through environmental protection measures necessary for construction and operation.

7. Chapter 5 – Characteristics of urban mass transit systems in the surveyed cities

7.1. Organization and financing

Most cities with extensive public transportation systems have an authority, usually governmental, that is charged with coordinating or managing all public transport modes within the urban area. The form of these arrangements varies widely among the cities that responded to the survey.

The responsibility and level for transport policy decisions varies among the investment, operation and development aspects of the transportation network. The State (Country) and the City typically are both prominent in investment issues. The Operating Authority predomi-

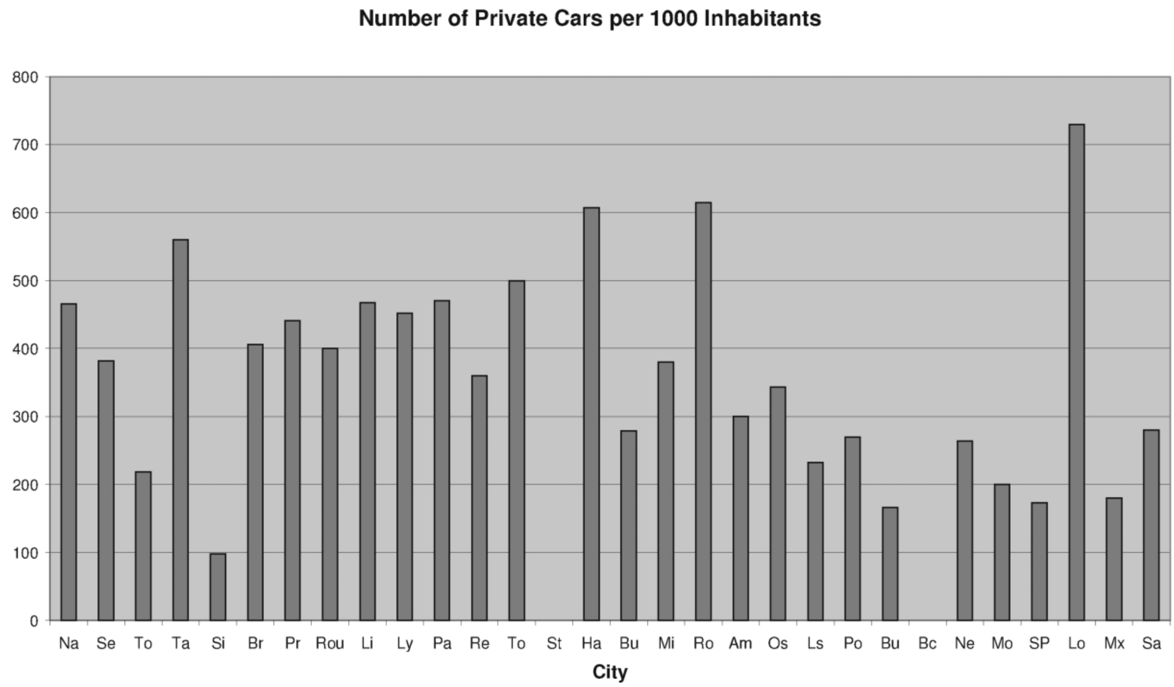

Fig. 3. Number of private cars per 1000 inhabitants.

nates in operational issues and the City takes the lead in development issues.

The level of financing for transportation infrastructure investment by the various potential partners varies over the full range from location to location but the median values reported are: operating company 26.8%, local community 43.7% and State (Country, Region) 26.6%.

7.2. Transport policy

The driving force behind providing mass transit has always been to facilitate the effective movement of people in urban areas. Such systems provide a means of transportation for the public that do not use private vehicles and provide good mobility in an urban area when traffic congestion is severe. The success of transit systems is thus strongly related to difficulties elsewhere in the transportation system, e.g. chronic road traffic congestion on city streets and arterial roadways.

City authorities face difficult decisions in many urban areas. A city center needs transport access to thrive economically but unrestricted access and/or the availability of no transport alternatives leads to severe traffic congestion which affects economic growth—as well as providing a poor environment and frustrating conditions for city users. Cities have addressed this problem by a variety of approaches in planning and regulation.

The proportion of car ownership in a city is a partial indicator of anticipated congestion problems along with population density, available road network, etc. The cities responding to the survey had car ownership rates that ranged from a low of 98 cars per 1000 residents in Singapore to a high of 730 cars per 1000 residents in Los Angeles. Singapore limits car ownership by a permit system as well as discouraging use of private cars in the city center and on congested freeway sections during peak hours through an electronically administered fee collection system. Generally, the only discouragement to car ownership in most cities, besides the basic financial ability to afford a car, is congestion in the particular Metropolitan area. Car ownership in other cities responding varies between these extremes with both the average and mean car ownership being approximately 380 cars per 1000 residents.

In order to allow the city center to function properly, 13 cities reported policies to limit the use of private cars in the city center and 21 cities reported special parking policies. These policies often distinguish between city center residents and other city users so that the city can remain a viable place to live. Twenty cities have underground parking in the city center and many cities have policies requiring a certain number of parking places to be provided for new buildings in the city. These regulations help remove parked cars from the streets but contribute to the encouragement of the further use of cars in the city center.

Fifteen cities indicated that they have policies that are designed to encourage the use of public transport and 18 cities indicated that they are using recent developments in transit system technologies that are designed to reduce construction or operating costs under various urban conditions (Fig. 3).

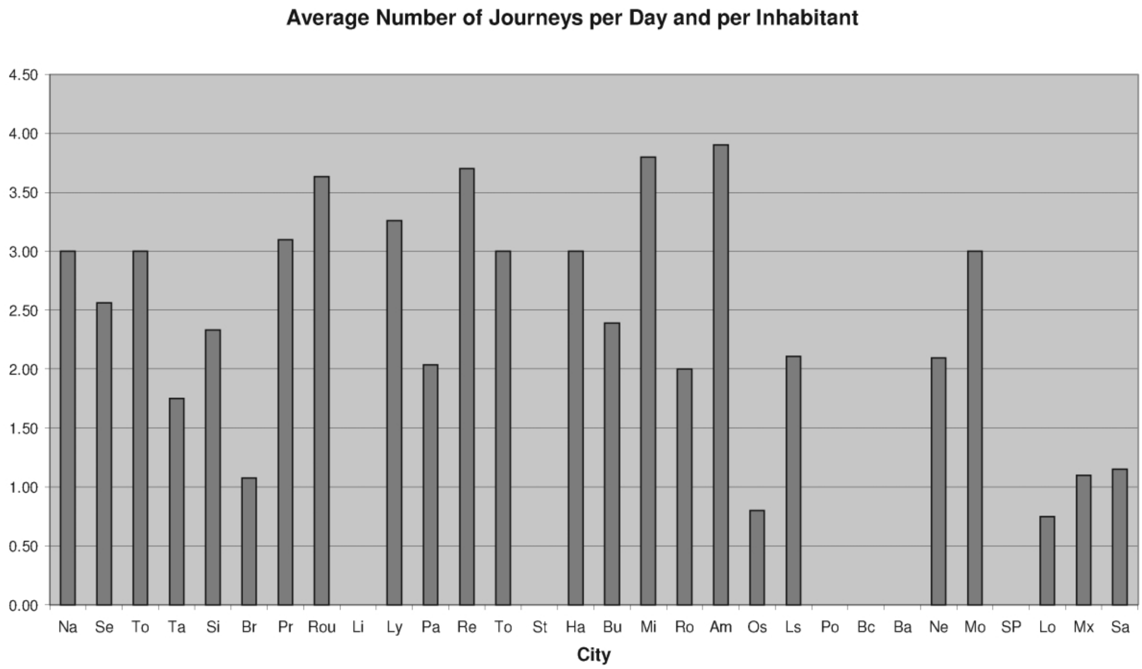

Fig. 4. Average number of journeys per day and per inhabitant.

The net result of the varied evolution of transportation conditions, governmental regulations and transportation planning initiatives in the responding cities is a wide range of patterns of transportation and usage. The average number of journeys per day per inhabitant varies from approximately 0.8 in Los Angeles and Oslo to a high of approximately 3.8 in Amsterdam and Milan. The average and median of the city statistics are both approximately 2.4. In terms of use of public transport systems, this ranges from a low of 6.5% in Los Angeles to a high of 82.6% in Mexico City. Again, the average and median of the data provided are very close to each other at approximately 38% of journeys made by a form of public transport (Fig. 4).

7.3. Current network and modal split

As indicated earlier, the cities responding demonstrated a vast range of city and transport network characteristics. At a small scale, the City of Strasbourg has 1 light rail line and 26 bus lines with a total route length of 300 km and an annual number of journeys of 12.8 million. At the other extreme, the Tokyo area has 12 872 km of lines with 15.4 billion journeys per year and the City of Sao Paulo has 1655 routes, a total line length of 31 174 km with 3.2 billion journeys per year. A breakdown among types of transport systems for the Paris region is given in the Table 3.

7.4. Future expansion

All but a few of the cities responding are expecting to expand their systems within the 5-year, 10-year or 20-year horizon. Only 4 cities—Brussels, Hamburg, Lille and Newcastle—did not mention expansion of their mass transit lines. The total additional line length expected for the remaining 24 cities is 2320 km. The median values for the expected expansion of each mode in each responding city are:

1. 50 km of regional Metro and suburban trains,
2. 16 km of Metro and automatic systems,
3. 22 km of light rail and tramway, and
4. 13 km of bus and trolleybus.

Table 3
Characteristics of mass transit systems in Paris

System type	Number of lines	Total line length	Annual journeys (10^6)
Regional metro and suburban trains	26	1400	901
Metro and automatic systems	17	216	1172
Light rail and tramway	2	20	17
Bus	254	2746	809

Table 4
Approximate construction costs for fixed guideway systems

	Regional metro and trains				Metro and automatic systems				Light rail and tramways			
	At grade	Elev.	Cut and cover	Tunnel	At grade	Elev.	Cut and cover	Tunnel	At grade	Elev.	Cut and cover	Tunnel
Max	37	111	313	313	150	150	276	276	25	60	110	160
Min	3	4	8	7	1	6	6	7	2	6	23	27
Average	13	31	142	126	29	42	69	82	11	25	50	70
Median	6	14	100	51	18	31	42	62	11	17	34	60

Note: The numbers represent average costs in millions of $US per kilometer of line, adjusted to a January 1995 value, land acquisition included, rolling stock excluded (except as noted in individual responses).

8. Chapter 6 – Cost ranges for urban mass transit systems on exclusive rights-of-way

8.1. Construction cost ratios

As described in the introductory chapters, the overriding issue for decisions regarding aboveground or underground transit systems is an almost universally perceived higher initial capital cost for underground systems—although, as noted previously, this is not universally true.

The questionnaire asked responders to provide information about the cost of three different types of systems (Regional Metro and Suburban Trains, Metro and Automatic Systems, and Light Rail and Tramways) and four different types of vertical alignment (at grade, elevated, cut-and-cover, and tunnel). Table 4 below shows the aggregated data reported for actual costs in millions of $US per kilometer of line and the graphs (following) show the relative costs reported for the different alignment options. The ratios may vary among the relative costs since data were not provided for all alignment options for all cities.

The cost data show a very wide variation for all alignment options—well over an order of magnitude for most system types and alignments. The maximum cost for a tunneled regional Metro or suburban train is more than 100 times the reported minimum cost for such a system at grade. Because of the large variation and the influence of a few expensive projects on the average cost, median costs should be more representative of the differences among alignment costs over a wide range of conditions. Such large variations are likely due to (at least) the following factors:

1. For at grade systems, land and track may already be available in an existing systems and the reported cost of the new system may be mainly a refitting of a largely existing network.
2. For the underground work, the most expensive projects are many times as expensive as other projects—the cost range for underground alignments is approximately 40 times for both regional rail and Metro systems and is over 5 for light rail and tramways.
3. Differences in cost structures, exchange rates, reporting accuracy, what is included or excluded in the projects and, country or regional differences.

The Working Group emphasizes that cost data was not reported for all systems from all cities, that cost comparisons—even within one country or region—show very significant variability and, none of these data could be independently validated.

Therefore, the above cost comparison data, and the conclusions drawn from it, should be viewed cautiously and used very carefully, with qualification as to the level of accuracy implied.

8.2. Relative costs

Sensitive to the above cautions, the ratios of cost among alignment options were calculated for each system that had comparative data and then these relative costs were analyzed as to maximum, minimum, average and median ratios. The data from the analysis are presented in Figs. 5–7 below.

8.3. Typical costs ranges

Elevated construction costs were reported from 0.7 to 7.5 times the cost of at-grade construction with the median cost ratios ranging from 1.3 to 2.3 for the 3 system types (rail, Metro and light rail).

Cut-and-cover and tunneled construction costs were reported from 0.9 to 37.5 times the cost of at-grade construction with the median cost ratios ranging from 2.8 to 5.8 for the 3 system types.

The median of tunneled construction costs were reported from 1.0 to 2.0 times the cost of cut-and-cover construction although tunneled construction can be less expensive in direct cost when land prices are high (e.g. Sendai).

An update on the previous 'rule-of-thumb' used to compare conceptual direct costs would be to narrow the range of typical cost ratios, i.e.

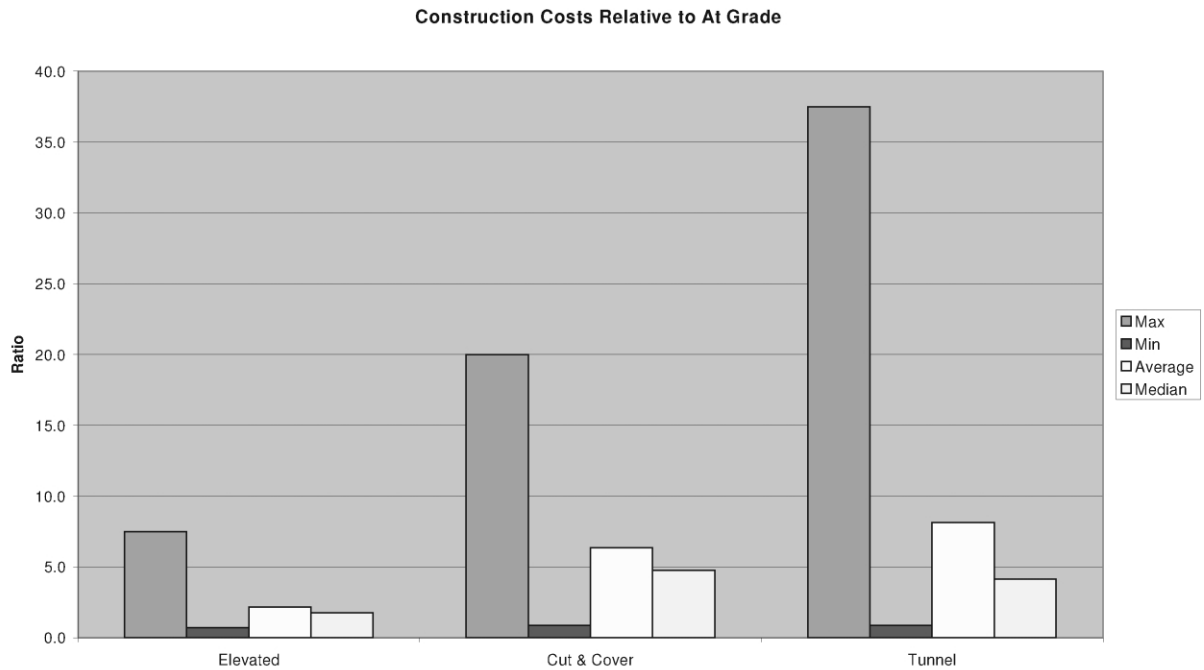

Fig. 5. Construction costs relative to at-grade.

	Surface	Elevated	Underground
Existing perception	1	3	6
From the questionnaire analysis	1	2	4.5

The Working Group stresses, however, that these ratios should not be used to limit options for analysis in the conceptual stages of transit system and alignment planning. The potential variations in circumstances, surface constraints, land prices and geological conditions are huge and the direct construction cost is only one element of determining the right alignment choice. The indirect costs and potential environmental impacts of surface and elevated alignments are additional real costs of a transit systems even if not directly borne by the transit agency or not immediately felt in terms of city development.

It is a trend that it is becoming increasingly difficult to site new transit networks at grade in many cities and that increasing land cost plus mitigation cost for environmental impacts of surface and elevated solutions are narrowing the cost gap between at-grade and elevated with underground construction.

8.4. Operational costs

No data were collected on differences in operational costs of the various alignment and grade options—although it is generally accepted that underground systems are more expensive to operate than elevated or surface systems. Some of these costs arise from the nature of underground spaces—requiring ventilation and lighting and increased staffing for safety concerns—but this may be offset by other factors, such as freedom from the elements—rain, snow and ice for example—for underground systems. However, some of these increased operating costs increase reliability of service, comfort, quality and ease of use.

Data were collected on the percent of operational cost met by direct fare revenue. These ranged from a low of 25% in Rome to a high of 144% in Mexico City. The average percentage is 59% and the median percentage is 50%. The local City or Region normally has the largest role in underwriting the shortfall in operating expenditures.

9. Chapter 7 – The choice, underground vs. aboveground

9.1. Percent of urban metro systems at-grade, elevated and underground

The cities responding provided data on the distribution of their networks between at-grade, elevated and underground alignments. The average and median data are shown in the Table 5 for the three types of systems considered.

The table shows that the overwhelming choice for Urban Metro systems is underground with very little at-grade alignment. They are typically designed to be high speed, high capacity systems serving the city center and

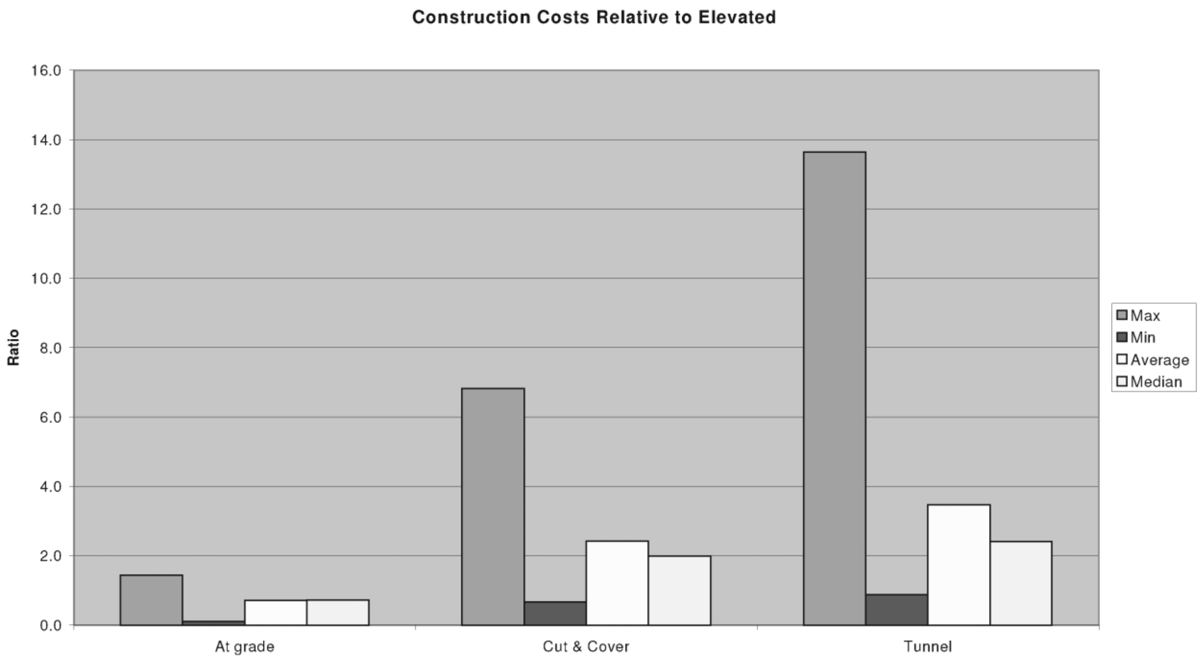

Fig. 6. Construction costs relative to elevated.

hence need a grade-separated alignment for much of their length.

The table also shows that the overwhelming choice for regional Metro, suburban trains, light rail and tramways is at-grade alignments. These systems are often an adaptation of an existing rail network or are designed as a low-cost, medium speed, medium capacity service to operate on existing street rights-of-way.

9.2. Discussion on the choice between elevated and underground

Eighteen of the 30 questionnaire responses indicated that there had been a general debate about the choice between 'elevated' and 'underground' within the context of the choice of the public transport system. The same number of responses indicated that there had been a general debate about the choice between 'elevated' and 'underground' related to the vertical alignment of the chosen public transport system. However, the results were not all the same. In some cases, once the general parameters of the transit system were fixed, the options for actual implementations of the line were very limited. In other cases, the choice of vertical alignment occurred in the design of individual lines or segments of lines.

The most common reason for use of the underground was its necessity in the penetration of the existing urban fabric (25 responses). Environmental preservation (19 responses) and the crossing of natural obstacles (20 responses) were the next most common reasons for choosing the underground. Difficult topography was an important factor in 12 responses and climatic protection only in 4 responses (Nagoya, Sendai, Brussels and Mexico City). Other reasons were cited in 9 responses. These reasons included: historical preservation, land acquisition problems, public and media opinion, leaving more space at the surface for pedestrians, less construction impact on traffic and noise.

Fifteen of the responses indicated that specific case studies were available that compared elevated and underground solutions. In sections of line where both elevated and underground were considered feasible, the elevated solution was often chosen because of its lower initial capital cost. In some cases, the underground was considered the only feasible alternative and, in some cases, an otherwise acceptable aboveground section was not possible because of the problems in transition between the underground and elevated sections. In Sao Paulo and San Fernando Valley, studies showed the underground solutions to be cheaper than the elevated solution as well as preferable in terms of environmental impact.

9.3. Choice between cut-and-cover and tunneled construction

The choice between cut-and-cover and tunneled construction was mixed in the responses received. The main determinants of the choice were the relative construction cost and the relative impact on traffic and businesses during construction. Some cities found the costs of cut-and-cover and tunneled options to be relatively close in terms of construction cost. One city (Amsterdam) indicated that the line costs were similar for both options but that the station costs were higher for the tunneled

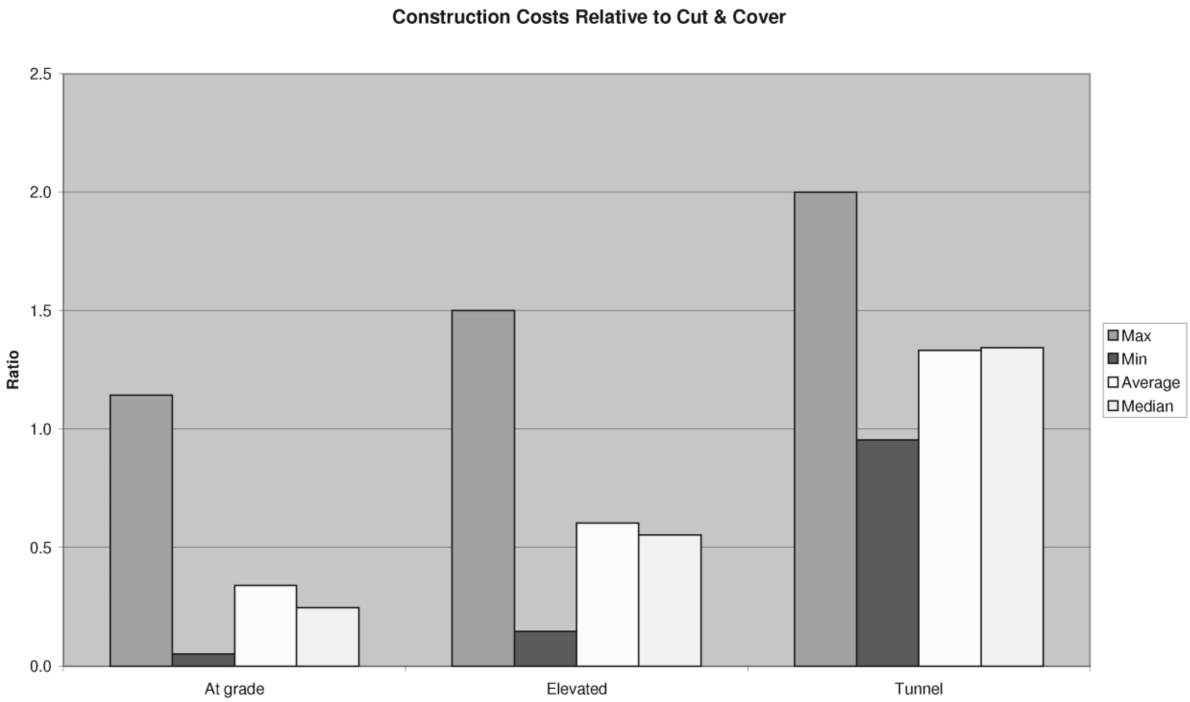

Fig. 7. Construction costs relative to cut-and-cover.

Table 5
Comparison of at-grade, elevated and underground by transit type

System	Indicator	Percent at grade	Percent elevated	Percent underground
Regional Metro and Suburban Trains	Average	73	10	16
	Median[4]	92	2	5
Urban Metro and Automatic Metro	Average	19	23	63
	Median	7	10	78
Urban Light Rail Tramways	Average	87	27	10
	Median	98	2	9

option; one city (Singapore) indicated that the tender for a bored tunnel was significantly less than for the cut-and-cover option. Cut-and-cover construction was chosen in Lille because the cut-and-cover alignment allowed a better urban solution. In Budapest, cut-and cover construction on a wide, major street was also used as an opportunity to replace aging utilities. Tunneled construction was used in several cities to preserve trees, historical areas and minimize surface disruption to pedestrian areas. It was indicated by the City of Tokyo that public opposition to cut-and-cover construction has increased significantly in Japan.

9.4. Indirect advantages from underground mass transit

9.4.1. Time savings

Sixteen cities indicated that time savings were an important indirect advantage of underground alignments and a number of statistics for time saved were provided. The underground lines provided faster average speeds than alternative surface transport modes (bus or tram) saving up to 1 h/day in commute time (Budapest). In Taipei, it was estimated that the Tamshui line would save approximately 4 700 000 min/day of public trips, and 1 550 000 min/day of private vehicles in the year 2001. Fully grade-separated surface and elevated solutions can offer similar time savings to underground alignments but may not be an option due to the other issues cited in the questionnaire.

9.4.2. Reduction in the flow of private car traffic

Eleven cities indicated that there had been a significant impact on private car traffic. In Tokyo, it was reported that the availability of mass transit has meant that the number of cars in the region is perhaps 15 million less than would be the case without the transit

[4] Median means half of the data is above this value and half is below.

Table 6
Examples of quantitative cost reductions where Metros are used

City	Pollution	Congestion	Accidents
Sendai	1660 tons of CO_2, 3.3 tons of NO_x and 0.5 tons of SO_x		
Tokyo	12.7 million tons of CO_2, 8600 tons of NO_x and 2940 tons of SO_x in Greater Tokyo		1160 less lives lost, 85 620 less injured per year in Tokyo, Nagoya and Osaka
Taipei	Emissions are expected to be reduced by 2–10%		
Rennes		25% less bus journeys and 6000 less vehicles per day in city center.	
Mexico City	Metro reduces pollution by 10%		

system. In Sendai, it has been estimated that opening a new underground line reduced the number of cars and buses entering the city center per day by 2000 and 2150, respectively. In Rennes, it has been estimated that the VAL system reduced private vehicle mileage by 5.8 million km per year. In Toulouse, private car traffic dropped by 5%. In Mexico City, increases of traffic speed of 20–30% were common when a Metro line followed an existing street system.

9.4.3. More space for pedestrians

Twelve cities reported significant benefits in allowing the creation of pedestrian-only streets, squares and parks. For example, in the City of Toulouse, 50 000 m^2 of pedestrian areas have been added since 1991.

9.4.4. Reduced space consumption

Responses echoed the savings indicated above in terms of more space for traffic, more space for pedestrians, and more open space.

9.4.5. Urban development

Twelve cities indicated that urban development issues were an indirect advantage of an underground alignment. Development and land prices tended to increase close to underground stations and the Metro was considered to be an important starting point for urban development (e.g. Mexico City).

9.4.6. Energy savings

Energy savings were listed as an indirect advantage by 12 cities although many had no specific figures available. It was indicated that, in the greater Tokyo area, 4.12 billion liters of oil per year were saved through the use of mass transit. In Hamburg, a comparison between the specified energy consumption in kW per person per km for Metro trains vs. private cars showed a ratio of 1:3 (based on a load rate of 20% for the Metro and 1.3 persons per car).

9.4.7. Reduction in external transport costs: pollution, congestion, accidents

Ten cities indicated significant savings in external transport costs but only a few had specific quantitative data. Examples given of quantitative reductions are given in Table 6.

10. Chapter 8 – Findings and recommendations

As a result of discussion and analysis of the 30 responses to the questionnaire on Underground Urban Mass Transit Systems, the International Tunnelling Association Working Group 13—Direct and Indirect Advantages of Underground Structures—offers the following findings and recommendations.

10.1. Findings

1. The decision on whether to place an urban mass transit system underground or aboveground is a complex planning, engineering, construction, urban design, economic and political decision.
2. In many cases—for example in the center areas of older cities—for functional, social, historic environmental and economic reasons there is no alternative to the choice of an underground alignment for new mass transit systems.
3. For many developing countries, the investment cost of a fixed guideway urban mass transit system is significant compared to the national or city economies. For urban mass transit systems developed or operated by private companies, return on investment is a critical issue.
4. For newer cities, cities without extensive historical districts, and cities with wide streets, elevated alignments can offer full grade separation typically at substantially lower initial construction cost than underground alignments, with certain exceptions usually related to right-of-way costs.

5. The initial capital cost is only a part of the total long-term financial commitment. Costs include capital (including financing), operating, maintenance, security and rehabilitation.
6. Consideration of all costs—including capital, operating, maintenance, security and rehabilitation costs are necessary.
7. Consideration of all benefits—direct and indirect, short and long term—are necessary.
8. Long-term benefits such as increased economic activity and urban development potential are frequently not calculated in making the choice of whether to place an urban mass transit system underground or aboveground.
9. For the choice to be made well, both short and long term costs and short and long term benefits need to be objectively and comparatively considered.
10. Many aspects of the cost-benefit relationships are hard to quantify. Reference analyses and reports with the experience of other cities are very useful—particularly in the early stages of planning and design.
11. The problems of elevated alignments relate to availability of sufficient right-of-way, and the long-term environmental and real estate impact of elevated transit alignments. There is little quantitative data on which to base such decisions although there are many examples of older elevated railway alignments that have been removed due to public objections or to reverse urban blight.
12. In areas outside the city center, at-grade and elevated alignments offer the ability to construct greater lengths of transit system at the same initial capital cost or to lower the investment cost of a system of fixed size.
13. A cost ratio typically assumed for surface vs. elevated and vs. underground systems has been reported to be 1/3/6. Analysis of the data received from this questionnaire showed very large variations in cost ratios according to the particular circumstances of each city and existing infrastructure—which means that such rations are not very useful in practice. The median ratios from the data received for this report were approximately 1/2/4.5.
14. Working Group discussions confirmed that (with some exceptions) the relative costs of underground systems relative to surface and elevated systems are tending to narrow. This is particularly true in areas of high land value and as environmental restrictions on surface and elevated construction monetarize the differences in land and environmental impact. Better technology and productivity for underground construction methods are also helping to narrow this cost differential.
15. Underground construction costs are tending to fall with time, as technologies and productivity improve. However, the costs of underground transit systems may not reflect this due to the fact that higher standards of amenity and safety are being built into new underground systems, e.g. large volume public spaces, air conditioning systems, better surface finishes etc.

10.2. Recommendations

1. The choice of underground vs. aboveground for urban mass transit systems must be made by each city considering each area of the transit system, based on its own specific circumstances.
2. Few cities, which have had Metro systems in use for a substantial time regret the choice to build that system and, in general, to place it underground near and adjacent to the city center.
3. The above statement, and the economic/cost environment which supports it, should be documented and publicized to assist decision-makers in making choices for new Metro systems.
4. Cities and transit agencies that undertake specific studies of the relative advantages and disadvantages of underground transit alignments, especially those including long-term cost/benefit information, are encouraged to publish their analyses and findings for the benefit of other decision makers around the world.
5. The critical decision between an underground and an aboveground alignment in many cases is strongly, if not completely, influenced by the issue of perceived high initial capital cost. This decision should, however, consider the benefits of increased long-term social and environmental improvements and beneficial economic development.
6. Representative decisions for specific mass transit systems should be documented and illustrated by reference to current and retrospective studies of typical projects (including those older than 20 years), considering all costs and benefits, real and perceived. Estimates of changes in land value and perceptions in changes in environmental conditions close to alignments and, quantified estimates of all the benefits that have accrued to the region because of the particular project, would be of particular interest. Examples of elevated vs. underground road alignments would also be pertinent.

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Appendix B: Questionnaire data categories

B.1. Part 1: Data and information concerning the city

1. Geography
   1.1. Area
   1.2. Population
   1.3. Topography
2. Geology/Hydrogeology
3. Economy
4. Urban fabric
5. Historical and archaeological heritage

B.2. Part 2: General points concerning urban transport

1. General transport policy of the city
   1.1. Policy with regard to the use of private car
   1.2. Policy with regard to parking
   1.3. Policy with regard to public transportation systems
2. Modal split

B.3. Part 3: General points concerning public urban transport

1. Organization
2. Current extent of operated lines and traffic
3. Anticipated Future Developments (10, 15, or 20 years)

B.4. Part 4: Public transport on exclusive right-of-way

1. Financing of the infrastructure development
2. Construction costs
3. Financing – Operational expenditures
4. Types of current infrastructures and present expenditures
5. Choice between 'aerial' and 'underground'
6. Choice between 'cut-and-cover' and 'tunnelled construction methods'
7. Indirect advantages obtained from underground transportation

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