How to Build a Metro for Half-price or Less

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Synopsis:
Worldwide metro lessons show that some principles cannot be exported from one country to another but that others are Golden Rules that should be applied universally. The most fundamental rule is that “time is money”. Other fundamentals are a) to enact enabling legislation to obtain property (real estate) in a reasonable time b) to spend money wisely at an early stage and c) to ensure that project planning is joined up with non-project planning and other community or city requirements. The enabling legislation must be a top-down affair that gives government the power to make decisions which benefit society as a whole. An example of two different projects is given; one where streets are dug up and one where cut-and-cover work is kept within city block footprints and street impacts are minimized. When digging up streets is avoided both design and construction time can be reduced by so many years that, when used in conjunction with the previously mentioned enabling legislation, costs are likely halved. If the metro authority is allowed to develop property within the taken city blocks and has the rights to let (or even sell) that property then the entire railway construction cost can probably be recovered in a ten-year period.

1. What cannot be exported from one country to another

The experience from one country cannot necessarily be directly translated and used in another country. There are many issues to consider which may be unique to a particular country. The main issues can be categorized under the following headings:

- Political issues
- Cultural issues
- Labor custom and practice
- Finance processes
- Procurement processes
- Legal issues (and this includes custom and practice on styles of contract as well as what this author calls “Enabling Legislation”)

1.1 Political issues

Political issues cover the style and system of government at both national and lower levels and how these different levels interact and work in practice. A good comparison here of the typical extremes might be the United States versus Singapore. In the United States we find there are not only State and Federal governments to be dealt with but also City and County rules and regulations. The political path to project completion is a maze of obstacles from conception onwards. Any single project may have politicians at up to six layers of elected bureaucracy to deal with and from differing political parties, each with their own objectives. This is not a recipe for rapid and objective decision making. Conversely the city-state of Singapore has a single level of government where things can get done and get done quickly. The contrasting time taken from inception to construction of large projects in, for example, a city like New York
and a city like Singapore can, in very large measure, be explained by these differing political environments.

Above all, one of the political essentials is the degree of transparency within the system. This means, inter alia, having rules for procurement and government and their bureaucracies that are clearly understandable and available. Absence of transparent mechanisms can lead to corruption; a topic that will not be discussed further in this paper. Environments that promote a protectionist policy by introducing hurdles in order to prevent non-local participation are clearly directly responsible for cost increases to projects. The intent of favoring local industry is undoubtedly well intentioned in terms of providing wealth and jobs but where a city is introducing a metro from new (or has not expanded the existing system for many years) such protectionism is a recipe for financial disaster. Metros are usually unique projects requiring specialist skills that transcend borders. They cannot be entirely serviced by local firms and local skills; importing expertise and technology is a prerequisite. Trying to restrict out-of-town, out-of-state or out-of-country competitors only encourages a closing of ranks which often results in cartels forming to carve up the work and a failure to adopt the most appropriate technology. The sad result is that the public pays too much for the end facility and that facility may not be as good as it could have been.

The same is true for specifications and supply rules that prevent foreign products from being incorporated. The "Buy America" legislation is an example of a political policy which can prevent the American public from enjoying the benefits of overseas development in certain technical areas of expertise and it can also result in the public paying more than necessary for the end product.

1.2 Cultural issues

Cultural issues comprise a very deep subject. They embrace the psyche of a nation or people and in some societies there are different cultural groups with different feelings and aspirations that need to be accommodated in the planning of the project. One of the most elemental issues is the extent to which a people or nation can accept the benefits of the many against the disbenefits of the few, which in turn impinges on issues such as individual rights and the importance these are given in the big picture. For example, in the United States the right to own property is a fundamental precept with links back to Colonial and Revolutionary days. This makes the implementation of the "eminent domain" principle far more difficult than what is expressed in most other countries as "compulsory purchase". Further, the history of the abuse of eminent domain has made public opinion support the individual's rights even more strongly. The other extreme of this issue might be a country like Italy where there would be project enabling legislation that allows the compulsory acquisition of real estate to fit the project schedule; the difference in the Italian model being that if a property owner feels he has been unfairly compensated his claim is dealt with after the acquisition. Some countries have reached compromise methods between these two extremes. For example, the Hong Kong Special Administrative Region has a history of the government or quasi-government project promoter negotiating compensation payments with building owners that many have considered to be above market rate. However, by making property owners more than happy the projects have proceeded on time or ahead of schedule and consequently were completed within overall budget.

Other important elements are project statutory approval processes and the requirements for consultation. The ability of the public to question and protest plans is long enshrined in many democracies, although the extent of this consultation and the speed of the process vary significantly. For example, the United Kingdom's Public Inquiry system for major projects is similar in many ways to a legal court procedure with an Inspector (the "Judge") presiding over an inquiry closely resembling a court of law with proponents and opponents lined up on either side with their respective lawyers. The process can be extremely lengthy in hearing all the "evidence" for and against before the Inspector reaches a decision. In fact, although this gives the public (and particularly opponents to the scheme) a fair opportunity to be heard, there is widespread recognition that the process has become too lengthy, time consuming and costly.

The public's attitude to development, change, environmental impact and big business are all fundamental to how a project will be perceived. The acceptance of projects and the ability of the public to protest in an influential way can have a significant impact on the speed and success of any large project. A culture of
protest, rather than simply accepting the imposition of change can frequently influence the outcome. In many Western nations there has grown a strong environmental lobby that opposes infrastructure projects, which are seen as having negative environmental impacts and/or promoting the interests of “Big Business”. Rational and objective decision making on the project benefits and handling of environmental impacts can often become subsumed into irrational debate.

1.3 Labor custom and practice

Although labor custom and practice may be considered a sub-set of the “cultural issues” heading, it is thought deserving of a special heading because of its overwhelming importance. Metros require large labor forces. This includes not only the various levels of construction workers from unskilled labor to highly skilled craftsmen but also the layers of professional staff necessary for design and implementation. For most territories the days of labor abuse are fortunately long gone. It is important for training and, if necessary, importation of labor and professional staff to be planned. Successful projects in the modern world rely on a well trained and happy labor force. Putting arrangements in place that give this result requires an understanding of the local practice and customs as well as knowledge of available skills. This applies whether “union shops” are operated or not, though a history and custom of a labor force capable and willing to multi-task rather than needing individual workers for individual tasks (demarcation) has a significant impact on the type and size of workforce required and thus a significant cost impact.

Many arrangements for certain trades or skills have evolved over history. A good example of this evolution, because of the linear nature of tunneling, would be that of tunnel miners. Tunnel miners need skills involving both brawn and brain. The key issue is that tunnel projects can proceed no faster than the face mining. This would seem to give the miners a position of complete power in terms of wage negotiations and hence tunnel workers are indeed usually well paid. The traditional structure that has developed in almost all countries of the world (but notably not in all of the United States) is for miners to work on a target-bonus system. In such a system it is imperative to set the progress targets fairly so that the base wage rate (paid when targets are not met) provides a sufficient living income and that bonuses (paid when daily or weekly targets are met or exceeded) provide extra money which the individuals perceive is well worthwhile for them to make. The gang has to work as a team to earn the bonuses, which means the “leading miner” has to control, supervise and discipline his own gang to make sure everyone gets the bonus benefits; slackers will soon get dropped from his team. By setting targets and bonuses correctly it is usually possible to optimize progress to match the capabilities of the available plant and equipment. Fixing a problem that is delaying production becomes everyone’s problem. Contrast this to a fixed wage agreement where there is no incentive for a miner to achieve a higher output level. In fact, the reverse is true; the longer the project lasts the longer he will be employed at that same location. In this example, a fixed wage agreement becomes a disincentive to progress, resulting in additional project cost.

It is important to understand the various trades, skills and professions that will be required for a project as well as their history and the local labor law context. To this must be added an understanding of the current market for those trades, skills and professions and what mechanisms for training a new labor pool or importing the skills are available and could be made to work in the particular locality. When training is deemed necessary, the source of the new recruit trainees must also be identified. For example, there might be a local smelting plant scheduled to close or perhaps one closing in a nearby town. In all cases it is necessary to think about available accommodation where an influx of people is required. The whole of this process takes detailed planning and promoters usually understand well that resourcing the people for a project is a basic essential. It is important for project promoters to get their governments to understand this also and they usually do. For example, labor and immigration departments may need to have regulations changed by legislation to facilitate an influx of imported workers.

Lastly, understanding of labor custom and practice is directly linked to project estimating. International price benchmarking is often impossible because of different labor practices. For example, as a result of existing union agreements covering the eastern seaboard area of the United States, one will find in underground construction approximately four times the number of personnel that exist in similar projects in Asia, Australia or Europe. Obviously therefore, an international benchmark price for a tunnel from
those continents cannot be used as a comparison for underground work in, for example, New York. Negotiating project wage agreements with unions and trade organizations in advance (in countries with a strong trades union establishment) may be helpful for control of outturn cost. Setting in advance the wage level mechanisms and, if possible, such things as strike prevention measures will give a far more reliable project cost estimate. If undertaken professionally by all those involved, a project wage agreement can eliminate practices that may have become outdated or inapplicable.

1.4 Finance processes, procurement processes and legal issues

These last three categories from the earlier bullet list are each subjects in their own right and too vast to be dealt with in any detail within this paper. The important issue in all cases is to always “think local” and not try to impose a model used overseas when that model does not fit the local circumstances. Imparting local knowledge and understanding means having local people within the project implementation team in senior positions. Some countries have unique ways of doing things while others use approaches that are common, or at least similar, to a group of countries sharing a related culture. The history of “common country groups” often goes back to the days of a colonizing power and its legacy of legal, commercial and linguistic frameworks. For example, French speaking countries will often share the same ways that are based on Napoleonic standards and Spanish speaking countries will likewise share their own commonalities which well pre-date modern day Spain.

The ability to acquire the real estate and property necessary for a project to proceed is clearly of fundamental importance and differing legal frameworks and property rights can make this a key project risk. In democracies that highly value the rights of the individual property holder over the needs of the wider community, simply obtaining the property necessary for the project can become a long and involved process.

Obtaining statutory approvals and being able to remove or relocate any obstructions, such as utilities, is fundamental to progressing any project; but for linear infrastructure projects, such as a metro, the risks can be enormous when parties with no intrinsic interest in the project are involved. In countries where utilities are state owned or heavily regulated this facilitating work may be relatively straightforward. This is particularly the case where the government or the utility owner is the project sponsor. In countries where the utilities are owned by private companies the ability to have these companies engage in the project may be severely limited. A particularly stubborn or slow moving utility company can seriously delay a project or may even hold an owner to ransom. The introduction of legislation which curtails the power of utility companies can help control these high cost impact delays. However, a far more effective approach is to design the metro so that utility impacts are minimized and this means:

- avoiding in-street cut-and-cover work as much as possible and
- where possible placing stations off the streets.

2. The worldwide golden rules

The two fundamental “golden rules” are:

- “Time is money.”
- “Quality endures long after price is forgotten.”

The first is the most important issue relating to the title of this paper. In order to link this most important rule to an illustrative project and develop the conclusions for closing this paper the second rule will be dealt with first.

2.1 Quality endures long after price is forgotten

Metros have to last a very long time. No-one riding a railway that was originally designed for steam trains in the 19th century will be at all dismayed to learn that the original construction went over budget by
$200,000. Yet this budgetary control on construction contracts (just one element in the phase of project creation) is where we tend to concentrate our efforts in modern times. Even more important to remember is the lifetime cost of maintaining the facility. Skimping on small elements to save capital budget can result in maintenance spending that swamps the savings. This old quality maxim remains valid today and has to be taken in conjunction with the “time is money” adage. This is particularly true for moving and wearing parts of machinery, for finishes in public areas and most electrical and mechanical elements which usually have to endure for far longer than the originally specified design life. On many projects there will be research undertaken and committee meetings held to decide on something basic such as what paint or finishes should be applied to walls in public areas and the ranking often revolves around the capital cost. Imagine having a tooth filled at the dentist; the patient expects the filling to last a very long time and does not ask the dentist, “Do you have anything cheaper?” The situations are exactly similar. Even when the rankings are done correctly and the lifetime maintenance is factored in, an absurd decision can still be made because the owner’s representative only has direct control of the capital budget. The paradox is that the process of making these decisions consumes time but the time versus money curve has an exponential form. Therefore choosing plain steel washers over stainless steel (for example) may actually cost more, if the decision time is factored in, than selecting stainless without study at the outset. In reality, decision times for components and products can consume months in bureaucratic organizations. The product with the highest specification is probably the cheapest overall and making that decision quickly can give the discount in time savings that actually pays for the superior product. Designers and project promoters have a duty to future generations and this duty should not be taken lightly.

2.2 Time is money

This old adage would seem to be a statement of the ever-so-obvious. Yet the author has found this simple rule frequently gets lost in the fog of huge organizations and project teams and has concluded that

- budget overruns are almost always the outcome of time overruns.

Budgetary control is not simply for the construction phase or construction contracts. A new metro is something that starts with a dream, moves to an idea and then usually progresses to a feasibility study. Even after that point the railway is still a very long way from the building stage. Options have to be priced, conceptual designs developed, detailed designs worked up and contract documents drafted long before procurement processes can be started. This whole incubation stage costs money. The longer it takes, the more it costs. The longer it takes, the higher will be the bids received when contracts eventually reach the streets. This is the outcome of the way world economies work on a continuing inflationary basis. So all delays, even before any contracts are let, result in the owner (and ultimately the public) paying more. Every time a decision is delayed, at every stage and for whatever reason, the price goes up. Every time a previous decision is rescinded and changes are made, the price goes up. The key to delivering metros within budget (and there actually are examples of this happening) can be summed up in one word; the word is speed.

As the project moves through its various stages so the cost of every week of delay rises on an exponential curve. The delays late into construction, or worse, after construction (such as in the commissioning stage) are hugely expensive. Usually in the final reckoning true cost increases are neither calculated nor revealed; the true cost increase of course would include the unavailability of the facility for public use which means the additional costs lost, for example, in people’s travel times or for using alternative facilities.

The trick is to spend a good deal of money wisely in the early days. This needs to include things such as real estate acquisition and utility diversions. Putting off getting the land for work sites or buying the buildings that need clearing does not save money. In the final reckoning, delaying the acquisition costs more money than the real estate costs alone. This is because delayed acquisitions usually result in delay to the construction work itself and the construction delay costs are dear. This is difficult to explain to budget holders when there is no overall budgetary link and this is also why a single organization should be made responsible for realizing the metro. Unfortunately, because of the processes required for large infrastructure spending in the United States (budgets coming from different purses, a Record Of Decision
being needed before the real spending starts) the recommended seamless approach is not usually possible in the USA. However, it has been achieved elsewhere. A project that the author was involved in is used as the perfect example approach in Section 3 below.

3. The Hong Kong Island Line

The first phase of this metro project was about 13km long having 12 stations. The project was in a complex dense urban city with congested streets and difficult granular soil below the water table. This required open-faced shields (pressure tunnel boring machines were still in their infancy) for compressed-air mining in up to 3.5bars pressure. Extensive chemical ground treatment was also required. The design consultancy was let in December 1980 with design work starting in January 1981. The first trains were carrying passengers in May 1985, that is, less than four and a half years after the detailed design was awarded. The project was completed within the budget.

By comparison, the first phase of the Second Avenue Subway in New York (about 3.2km long with only four new stations and refurbishment and connection to an existing station) has been in the detailed-design and construction phases for over seven years at the time of writing without a tunnel drive being completed. To be sure, the political and legal issues have not be helpful in realizing the project but once construction started the utility conflicts from undertaking a cut-and-cover box in a major avenue of Manhattan have further increased delays and made the situation even more difficult.

The primary reason that the Hong Kong Island Line metro project was able to be built at this speed was that the entire planning cycle took cognizance of the “time is money” maxim by adopting the following principles:

1. The Government had enacted enabling legislation (called “the Railways Ordinance”) years in advance. This legislation empowered the Mass Transit Railway Corporation (MTRC) to acquire whatever land was necessary for the project and fairly compensate owners. In most cases owners were more than happy with the compensation received.
2. The Government enacted compressed-air working legislation years in advance after it was established by consultants that compressed-air working would be a principal method required for tunnel construction.
3. The areas required for the project (mostly for the off-line stations) were identified at the concept stage before detailed design was started. This allowed the acquisition process to be started early so that all properties were acquired before construction contracts were put out for bids.
4. Previous lines had been constructed using cut-and-cover station boxes in the main roads. This had caused immense disruption and the public had been outraged by the inconvenience caused. The entire concept was changed for this new railway so as to minimize taking space in the streets and largely to do away with cut-and-cover construction in the road. This was achieved by siting stations “off-line” (that is, to one or other side of the running tunnels) in city blocks. The areas needed were created by demolishing acquired buildings. Deep basements were built on the demolished sites and these became the station concourses, linked to the platform tunnels by hand-mined passenger adits. Each concourse basement was topped by a thick heavily reinforced transfer slab that was capable of supporting practically any design of high-rise building. The MTRC subsequently built tower blocks atop these slabs and the revenue generated from this real estate financed the entire railway.
5. Obviously, some street shafts were required for launching the tunneling shields and the locations for these, as well as the boundaries for each individual contract, were finalized at the concept stage. This allowed the street shafts to be designed in the first few months and let and built as advanced contracts while the remainder of the designs were being completed.
6. Utility diversions were also negotiated in advance and let and completed in those first few months.
7. The design consultants had extensive local experience and were able to specify in detail the method to be used for ground treatment areas. This had to be carried out from the surface to
start and complete the compressed-air soft-ground tunnel drives, to protect fragile buildings, to construct sumps and cross-passages, and so on. Deviations from the specified approaches were not allowed.

8. Similarly, ground treatment to be carried out underground for junctioning compressed-air work was specified in detail (sodium silicate and bentonite-cement grouting combinations) and deviations from what was shown on the drawings were not permitted.

9. Trucking of spoils was only allowed at night so as not to interrupt the regular traffic on the already highly congested streets. This meant day-time stockpiling (tunneling projects are nearly always worked on a continuous 24-hour basis for safety reasons). Where necessary, work-sites were decked to make multi-level space available in the restricted ground areas acquired.

10. The savvy contractors mitigated complaints and objections by liberal use of cash and by promptly fixing any damage caused to private property. For example, on one station where the top of a mountain had to be demolished with explosives many building windows were broken as a result of the thousands of blast rounds fired. By replacing all damaged windows with superior quality double-glazed units on the same day that a breakage occurred, and even paying disgruntled residents additional money “for their trouble” where it appeared appropriate, there were no work interruptions and no legal actions started.

4. **Conclusions: building your metro for less money**

No matter where a project is in the world, the enemy is always time. Lost time can hardly ever be recovered. When acceleration processes do recover some time it always comes at a premium cost. The primary reasons that metro output costs become so high are that insufficient attention to detail is spent in the planning and concept stages and owners do not stick with the decisions made in those stages. For example, it is always too late to leave property acquisitions and utility diversions to the detailed design stage. Each ‘repackaging’ iteration at the design stage causes delay and increases costs. Contract packaging and the contract boundaries need to be finalized at the concept stage and fully adhered to in the following stages. Packaging changes interfere with concept principles and cause a cascade of future problems.

Tunnels have a unique advantage in that their routes need not be constrained by the streets on the map. Yet because of the difficulties of way-leaves and archaic laws about property ownership this is exactly what happens in many cities. If it does not already exist, legislation is required to enable a metro route to go below buildings. Devising a route which is not constrained by the street map can result in considerable reductions to the lengths of tunneling required. The belief that streets provide a free corridor is entirely false; generally streets are utility corridors which means they are the worst possible places to drop shafts or do cut-and-cover work. The alternative, acquiring sections of city blocks to demolish buildings and construct basements for stations, allows the great majority of utility conflicts to be avoided. When digging up streets is avoided both design and construction time can be reduced so significantly that, even if property acquisition has to be funded from the capital railway budget, the net saving is probably of the order of fifty percent.

Fundamental requirements are a) to enact enabling legislation to obtain property (real estate) in a reasonable time b) to spend money wisely at an early stage and c) to ensure that project planning is joined up with non-project planning and other community or city requirements. Legislation must be a top-down affair that gives government the power to make decisions which benefit society as a whole. If the metro authority can actually be allowed to develop property within the taken city blocks (as was started in Hong Kong with the Island Line in the 80s) and has the rights to let (or even sell) that property then the entire railway construction cost can probably be recovered in a ten-year period.