Experiences in Seoul Subway Development

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1. Transportation in Seoul

1.1. Introduction

Seoul has been vitally functioning as a national capital of Korea for more than 600 years. Seoul Metropolitan Area (SMA) reaches an area of 11,776 km^2, includes 23cities, and carries 23.2 million populations. Seoul holds 44.2% (10.28 million) of the total population of SMA, and it is 21% of entire nation's population. In addition, Seoul is holding economic capability of 123 trillion Won accounting for 22% of total GNP. Population density of SMA, one of the most densely populated areas in the world, is 1,973 people/km^2. Seoul is located at the center of SMA, and her population density is 16,959/km^2, and 30 million trips (trip for means) in SMA are generated everyday from or to Seoul.

Hosting 1988 Seoul Olympic and 2002 Korea-Japan World Cup successfully, Seoul is expected to grow up as a main hub of Northeast Asia in the global perspective. Since the launch of subway Line 1 in 1974, total length of 287 km and 8 lines of subway has been constructed and in operation. Line 9 is under construction, and the extension plan of the existing subway lines such as Line 3 and 7 are actively in progress.

1.2. Population and vehicles

Population of Seoul is 10.28 million in 2003. The population had grown up by 1990 but tended to decline since 1990, because of the sprawl of SMA and the population migration triggered by the construction of new towns. Number of vehicles in Seoul reached to 2.78 million in 2003, and it has rapidly increased by 12% annually for last 20 years.

Year	Seoul			SMA (except Seoul)		
	Population (000)	Cars (000)	Density (per km^2)	Population (000)	Cars (000)	Density (per km^2)
1970	5,525	-	9,061	3,353	-	310
1975	6,879	-	11,458	4,035	-	364
1980	8,351	207	13,751	6,072	62	549
1985	9,626	446	15,899	6,234	155	563
1990	10,603	1,194	17,516	7,972	596	717
1995	10,596	2,043	17,491	10,000	1,995	903
2000	10,373	2,441	17,132	11,500	3,136	1,031
2003	10,277	2,777	16,959	12,963	4,007	1,161
Average increase rate	3.4%	12.0%	1.9%	3.7%	19.8%	4.1%

Excerpted from ‘Annual Statistical Report, Seoul, Gyeonggi Province, Incheon City’

Table 1. Population and vehicles in the metropolitan area

1.3. Subway and road transportation

Since the launch of subway Line 1 and Keongbu-Keongin Line in 1974, total operating length of subway of Seoul has reached to 345.4 km including national railroad as of 2003. Especially, half of the lines were opened in 1990's and currently 321 stations are operating. Total length of roads is 7,935 km and the average annual growth rate is 0.8% only and it has been less than that of subway since 1980.

Year	Subway		Road
	Length (km)	No. of station	Length (km)
1975	30.7	26	-
1980	69.7	53	6,610
1985	163.6	145	6,975
1990	165.1	147	7,374
1995	198.0	178	7,675
2000	336.1	311	7,889
2003	345.4	321	7,935
Average growth rate	9.0%	9.4%	0.8%

※ Subway includes Korean National Railroad.

Excerpted from ‘Seoul Annual Statistical Report’, Seoul Metropolitan Government.

Table 1. Subway and road in Seoul

Subway in Seoul is total 287 km of 8 active lines. Average ridership is over 6 million people per a day. Seoul Metropolitan Subway Corporation and Seoul Metropolitan Rapid Transit are responsible for the operation.

Categories/ Lines	Total	Seoul Metropolitan Subway Corporation				Seoul Metropolitan Rapid Transit			
		1	2	3	4	5	6	7	8
Route	8	Seoul station~ Cheonyangri	City hall~ City hall	Jichuk~ Suseo	Danggogae~ Namtaeryong	Banghwa~ Sangil Macheon	Eungam~ Bonghwasan	Jangam~ Onsu	Amsa~ Moran
Length (km)	286.9	7.8	60.2	35.2	31.7	52.3	35.1	46.9	17.7
Daily ridership	6,162	457	1,897	723	839	841	387	789	229

Excerpted from SMSC and SMRT statistics (2003)

Table 3. Operations of Seoul Subway

Modal share of Seoul in 2002 consists of subway 34.6%, personal vehicle 26.9%, and bus 26%.

Categories	Traffic volume (trips/day)	Modal share (%)
Personal vehicle	7,982,832	26.9
Bus	7,705,001	26.0
Railroad (subway)	10,284,673	34.6
Taxi	2,194,799	7.4
Others	1,512,971	5.1
Total	29,680,276	100.0

Including pedestrian trips (5,230,690/day), total traffic volumes by means in Seoul are 34,910,966. (Including subway transfer volumes)

Table 4. Traffic modal share in Seoul

1.4. Transportation policy

To meet the demand increase of cars by the economic growth and income increase, Seoul has been pushing policies oriented more to the automobiles than mass transit (subway and bus). Especially, having made efforts to settle the traffic problems by constructing and expanding new roads that connect new towns and satellite towns, Seoul has input tremendous amount of budgets for road construction projects. As a result, more demands for cars were created and a reverse effect was occurred, and the traffic congestion was not settled but worsened.

Number of personal vehicles in 2006 and 2011 are estimated to 3 million and 3.5 million respectively. Every household probably has at least one car. Due to the increase of the cars and trips, the traffic congestion of Seoul is likely to be aggravated.

To meet this trend in transportation environment, Seoul Metropolitan Government sets policy direction as follows:

- Promote modal share of public transportation by restructuring the system and improvement of service
- Improving congestion charge system to restrict entries of personal cars into CBD (Central Business District).
- Carrying out 'traffic-demand-saving urban development' which relates transportation planning with land use planning

Unlimited increase of cars causes air pollution, environmental degradation, traffic accident, and congestion cost, and end in declining quality of urban lives and the weakening of competitiveness of entire nation ultimately. Increase of inward or outward travels crossing the urban boundary of Seoul and long distance trips has been caused by regionalization of SMA, and it is main source of aggravated traffic problem of Seoul. 80% of the total cars are driver alone and inefficient trip patterns are furthered. Subway is more advantageous mode of transportation than others in regard of transport efficiency, environmental friendliness, stability, and land use efficiency, so that it may be considered as the most desirable means of transportation in 21st century and an optimal alternative to settle the transportation problems of Seoul and SMA.

To solve the traffic congestion and air pollution in Seoul, demand management policies that restrict car trips and policies to promote the use of public transportation are executing

- Try to increase demands of subway by constructing multi use transfer center for enhancing convenient transfer among bus, metro railroad, and cars.
- Use subway as mainlines that connect Seoul with SMA, and restructure bus systems to complement and connect mainline functions.
- Make subway plans and site development plans in a unified way by legislating to connect implementation of land use planning (site development and new town development) and transportation planning
- Induce to build subway a network connecting to existing mainlines by planning subway and site land development in a unified manner.

2. Subway development in Seoul

2.1. The 1st phase of subway

Seoul subway started in September 1970 by formulating the "Execution Plan of Subway Construction and Metropolitan Railroad Electrification". The plan included;

- Planning 5 lines and 133km subway networks penetrating Seoul CBD
- Construct 9.5 km Line 1 (from Seoul Station to Cheongryangri)
- Electrify existing national railroads and connect them to Line 1

The routes were selected to connect CBD and outer populated areas or developable suburbs, and the 1st phase subway network was finally designated after modification of routes and start/end points.

- Start from suburbs, linearly passing through CBD and ending at suburb. Extendable lines for future urban growth.
- Route should follow densely populated areas if possible, but severe curves must be avoided to maintain running speed.
- Evenly distributed traffic volumes among each lines
- Ensure sufficient distance between stations so that one station zone cannot place on the adjacent station zones.

Completion of the 1st phase subway network was epochal event, for it could provide Seoul with a systematic transportation network for the first time. Nevertheless, the transportation capacity of line 1~4 arrived at their limits soon due to the continuous influx of population, while budget deficit was too severe for city government and Seoul Metropolitan Subway Corporation, the operating body, to repay even interest itself. It resulted from the excessive concentration ratio that passengers were concentrated mainly on the commuting time and low use rate on other time zones. Routes and construction periods of the 1st phase subway are as the below Table 5 and Figure 1.

	Route	Length (km)	Construction period
Line 1	Seoul Station~Cheongryangry	7.8	’71. 4~’74. 8
Line 2	City Hall~Kangnam~City Hall (Circular Line)	54.2	’78. 3~’84. 5
Line 3	Gupabal~Yangjae	26.2	’80. 2~’85.10
Line 4	Sanggye~Sadang	28.3	’80. 2~’85.10
Total		116.5	

Table 5. The 1st phase of Seoul Subway

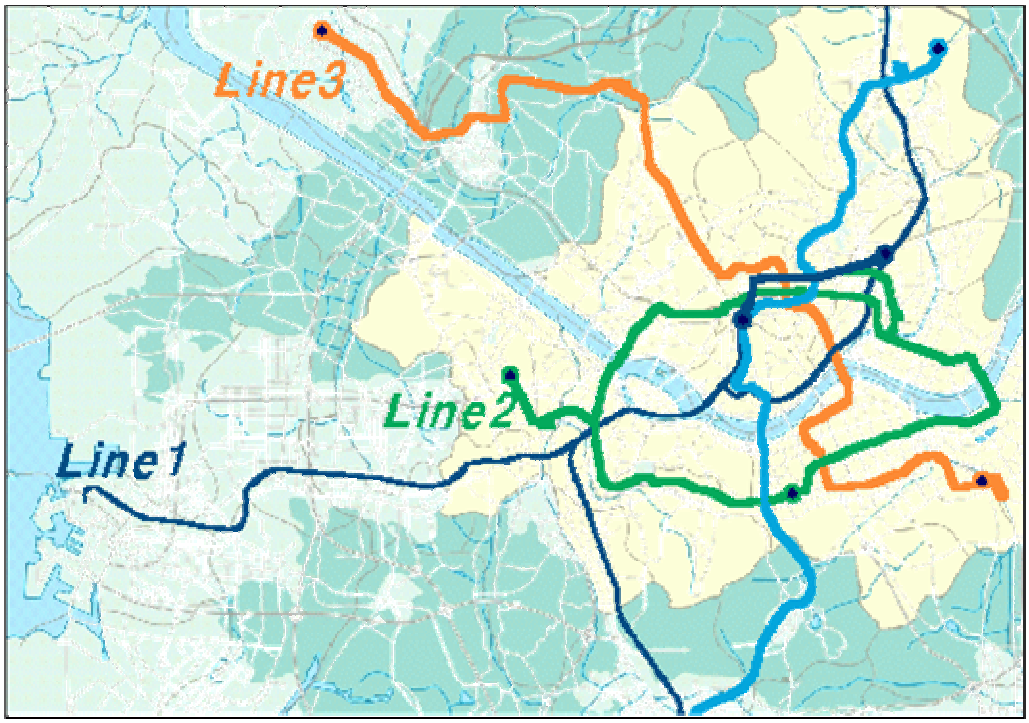


Figure 1. Map of the 1st phase of Seoul Subway

2.2. The 2nd phase of subway

After opening the1st phase of subway, the number of passengers increase 9~16% every year and the congestion was extremely aggravated. Urban transportation problems were raised as urgent issues, and Seoul Metropolitan Government set up "Construction plan for the additional subway lines". Distinctive aspects of the plan were the construction of additional branches connecting to existing lines, electrification of national railroads in city area, establishing regional express transportation networks by constructing 3 main lines passing through inner city, and adding station zones to non-serviced area. Based on "Feasibility Study for Subway Line Expansion", 4 lines of 160 km subway were constructed from 1989.

For the newly constructed 4 lines (Line 5~8), direct connection of operation to existing national railroad in suburban area was excluded to prevent over investment in adapting the latest operational systems and introduce AC/DC dual voltage trains. Sadang~Namtaeryeong on Line 4 was a node of regional network connecting to Gwacheon Line (Namtaeryeong~Geumjeong) constructed by Korean National Railroad. Extension line of Line 3 (Yangjae~Suseo) and Line 8 (Amsa~Moran) were planned under consideration of the link with National railroad Bundang Line (Wangsibri~Ori), a backbone line of Bundang new

town. Routes and construction periods of the 2nd phase of subway are as the below Table 6 and Figure 2.

	Route	Length (km)	Construction period
Line 5	Banghwa~Sangil (Macheon)	52.3	'90. 6~'96. 12
Line 6	Yeogchon~Sinnae	35.1	'94. 1~'00.12
Line 7	Dobong~Onsu	46.9	'90.12~'00. 8
Line 8	Amsa~Seongnam	17.7	'90.12~'99. 7
Line 2 extension	Sindorim~Kkachisan	6.0	'89.12 ~'96.3
Line 3 extension	Yangjae~Suseo	9.0	'89.12 ~'93.10
Line 4 extension	Sadang~Namtaeryeong Sanggyae~Danggogae	3.4	'89.12 ~'94.4
Total		170.4	

Table 6. The 2nd phase of Seoul Subway

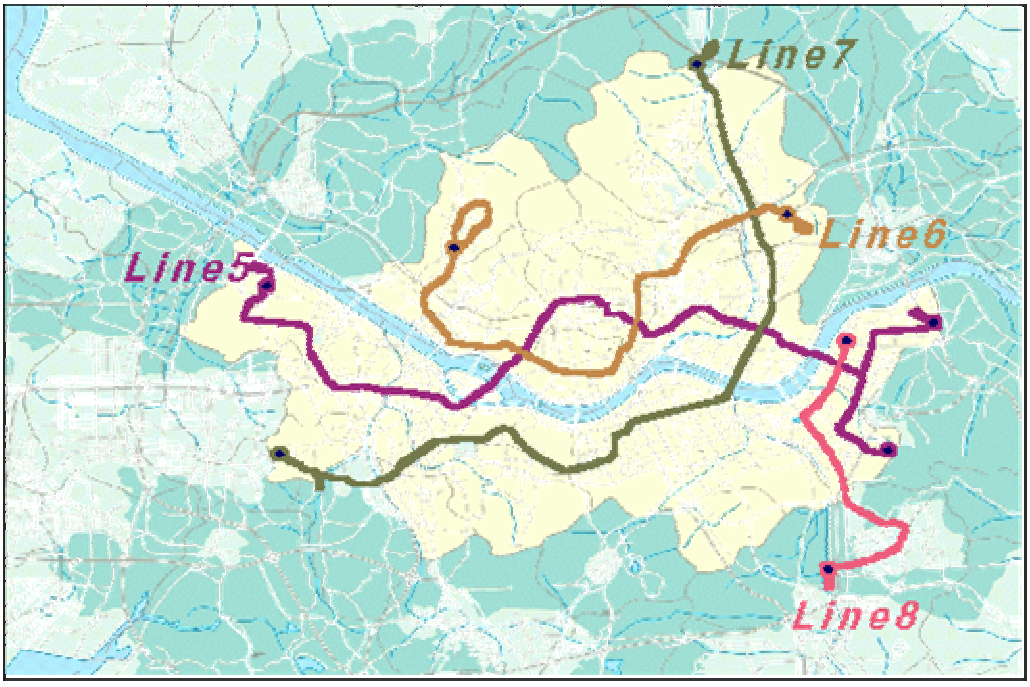


Figure 2. Map of the 2nd phase of Seoul Subway

2.3. Organizations for construction and operation

Office of Subway Construction (OSC) was established in 1970 in the city government for the construction of subway and was in charge of constructing Line1, while Seoul Metropolitan Government was operating after the completion of construction. During operation of Line 1, rapid increase of inner city population and number of subway passengers raised urgent need of additional provisions of subway Line 2, and OSC started to construct Line 2. But ensuring the source of budget supply was getting tougher, it was required that private corporation taking charge of subway construction and operation be established. During setting up the construction plans of Line 3 and Line 4, Seoul Subway Inc. was founded and started construction of Line 3 and Line 4 as a privatized project in February 1980. The organization was handed over to Seoul Metropolitan Subway Corporation (SMSC) together with Line 3 and Line 4 projects. As a result, OSC and SMSC were in charge of constructing Line 2 and Line 3 and 4 respectively, and SMSC took responsibility for the entire operation after the completion of each line.

The 2nd phase of subway construction was planned to restrict rapidly increasing car trips and to extend insufficient 1st stage subway networks, therefore new organization was required to accomplish this task. OSC disorganized in Sep 1984 just after the opening of the Line 2 in May 1984 was reestablished in Nov 1989 for the construction of the 2nd phase of subway. OSC started to extend existing lines of Line 2, 3 and 4, and to construct new Line 5, 6, 7 and 8. As the opening day of Line 5 approached, designation of operating cooperation was at issue. In conclusion, Seoul Metropolitan Rapid Transit (SMRT) besides SMSC was founded in Mar 1994 to operate the 2nd phase of subway.

2.4. Subway network expansion plan

2.4.1. Regional railroad (70 km)

Two express railroad lines that directly connect satellite towns to CBD are planned.

- Regional Line A (45 km): Ansan~Gwangmyeong~Yeouido~Seoul Station~Cheongryangri
- Regional Line B (25 km): Bundang~Yangjae~Gangnam~Yongsan

2.4.2. Subway (62.5 km)

One new subway line and 4 extensions are planned to meet transportation demand.

<New subway: Line 9>

Subway that connects east and west of Seoul along the Han River is being constructed. This line will be directly linked to Incheon International Airport Railroad.

- Length: 38 km
- Station : 37 (transfer station : 13)

- Ridership: 1,437 thousand people/day (year of 2028)
- Operation: local lines with rapid lines stopping only at transfer stations.
- Train: 6 cars (3M3T), capacity 870 people (L 20m×W 3.2m×H 4.3m)
- Frequency: 5 min (peak time: 2min)

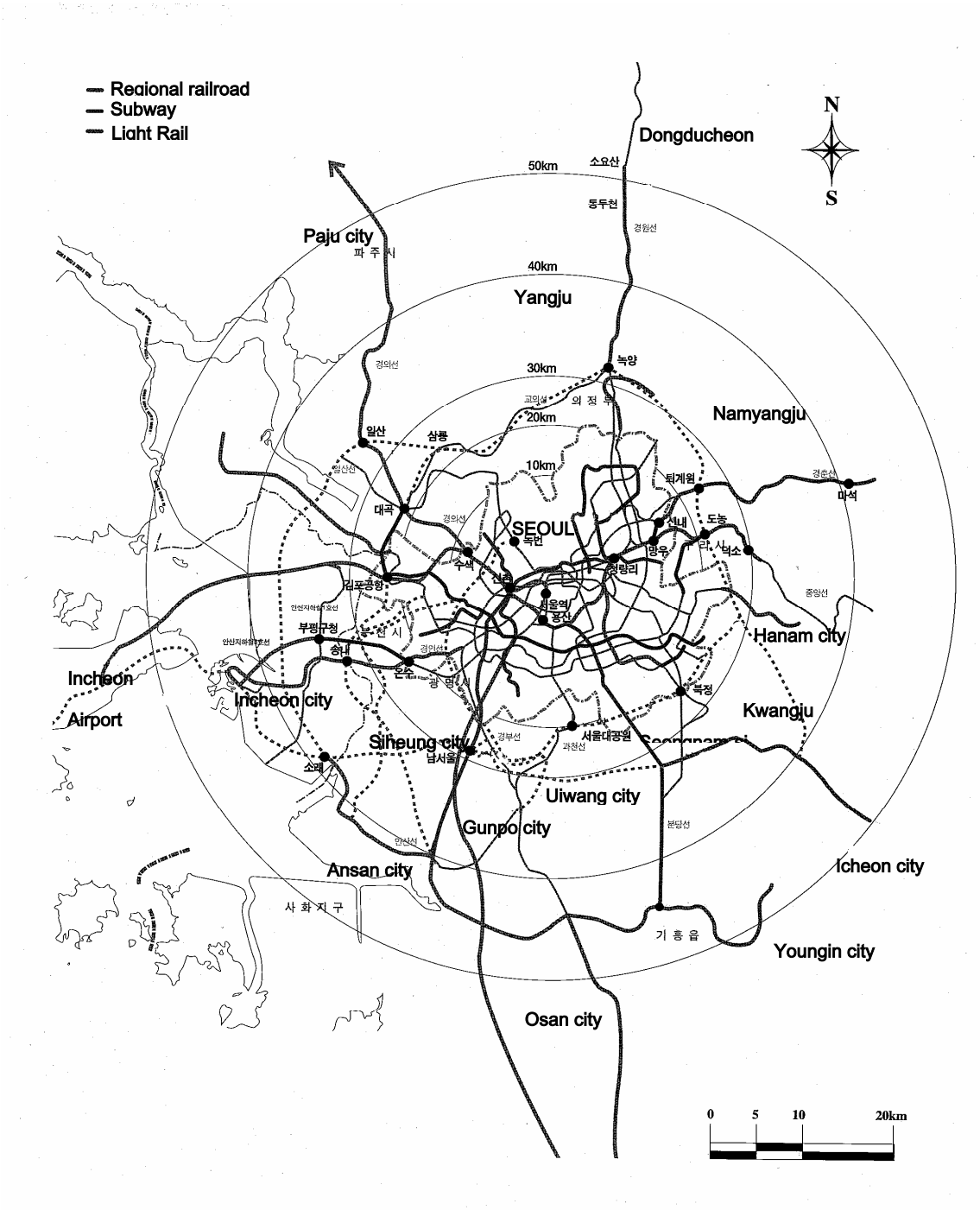


Figure 3. Subway expansion plan in the metropolitan area

- Electrical type: DC 1,500V
- Signal type: ATC, ATO
- Install platform screen door
- Budget investment plan
  - Seoul Metropolitan Government : 40%
  - Central government : 40%
  - Private sector : 20%
- Construction plan
  - 1st section: Kimpo Airport~Banpo 25.5 km (2001~2007)

  ※ Construction schedule of the 2nd section Banpo~Bangidong (12.5 km) depends on the financial situation and transportation demand
- Construction cost : 2.4 trillion won

<Extension of existing lines>

- Extension of Line 3 : Susseo~Ogeum (3km, started in 2004)
- Extension of Line 7: Onsu~Bupyeonggucheong (10 km, will start in 2004)
- Extension of Line 8 : Amsa~Guri
- Extension of Line 9 : Kimpo Airport~Daegok

2.4.3. Light Rail (61 ㎞)

Six lines are proposed.

- Sinrim-Nangok line: Yeouido~Noryangjin~Sinrim~Seoul National University, 15 km
- Mia-Samyang Line: Sanggye~Ui~Samyang~Sinseoldong, 13 km
- Mokdong Line: Sinwol~Mokdong Centeral Area~Dangsan, 8 km
- Wolgyae-Cheongryang Line: Sanggyaedong~Wolgyaedong~Cheongryangri, 14 km
- Myeonmok Line: Cheongryangri~Myeonmokdong, 5 km
- Eunpyeong Line: Eunpyeong Sinsa~Sinchon~Yeouido, 6 km

2.5. Subway and tunnelling technology

Advantages of bored tunneling for subway construction are as follows:

- Minimization of traffic congestion

- Solution for public complaints due to passing through private property (No need of aboveground building demolition)
- Easy to adopt a smooth curvature curve for train operation
- Construction cost savings for deep overburden

Based on the above advantages, tunnelling method has been adopted as a main construction method since the beginning of Subway Line 2 construction. Especially, New Austrian Tunnelling Method (NATM) applied for subway Line 3 and 4. It was the first large scale NATM tried in Korea and the conceptual revolution of safe tunnel construction given any geological conditions.

Even though some critics in the construction field of Korea were seriously concerned of NATM implementation at the early stages, local engineers carried out the tunnelling works successfully with foreign experts assistance. The merits of NATM were gradually accepted together with improved construction process and could mark a turning point to establishment and study of NATM technology.

Before 1980s, since the conventional ASSM method was limited to deep sound rock layers, tunnelling method in subway construction was not commonly used. However, since the adoption of NATM in the 1980s, the tunnelling method has been applied in many areas in order to prevent traffic congestion during construction. In the 1990s, tunneling method was applied even in under-river tunnel construction across the Han River in subway Line 5. Furthermore, in order to reduce blast vibration in metro areas, mechanical excavation methods adopting TBM and road headers were adopted and shield method has recently been adopted for passing soft layers.

2.5.1. Mainline tunnel

Around the tunnelling section along Yulgok street in Gwanghwamun area in Line 3, there existed cultural heritages, underpasses and large buildings, and the ground mainly consists of weathered soil with average overburden of 12 to 13 meters. For the above reasons, manual excavation by ring-cut method was performed.

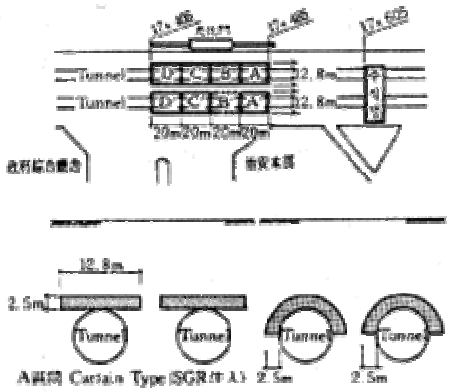


Figure 4. Section of injection method in Gwanghwamun area

2.5.2. Banpo river underpass in Line 3

1-Arch of twin track tunnel application in river bed area was replaced with 2-Arch type double track with lining concrete placement due to small overburden up the river bed and difficulty in passing soft ground. As auxiliary support methods, forepoling (1.5" steel pipes, L=2.5m), lagging sheet (B=280m/m, L=1.6m) was applied. As waterproof method, double tube packer methods with multi injection of suspension and solution, was applied. Injection test for test hole proved increase of N value by 2 times and hydraulic permeability decreased to K=10^{-6}~10^{-7}cm/sec.

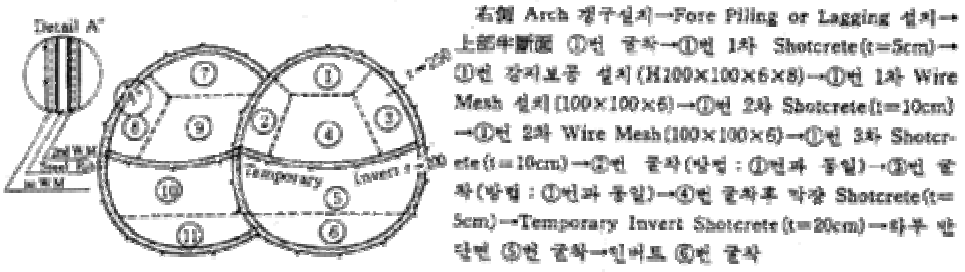


Figure 5. Cross section of 2-Arch tunnel excavation

2.5.3. 2-Arch tunnel station

Myeongdong station in Line 4 was located under existing Chungmu underground shopping arcade. It was the first tunnel type station and its geological conditions were fair.

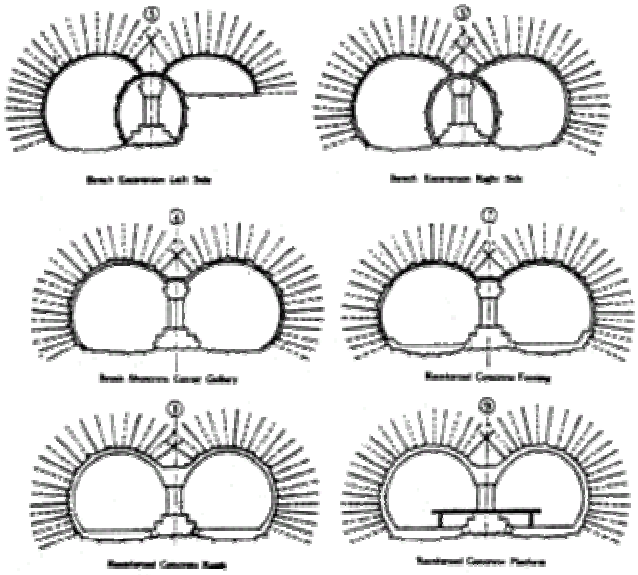


Figure 6. Construction procedure of 2-Arch tunnel type station

For septic tank passage section under the underground shopping arcade, neighboring construction with 1.5m distances were performed.

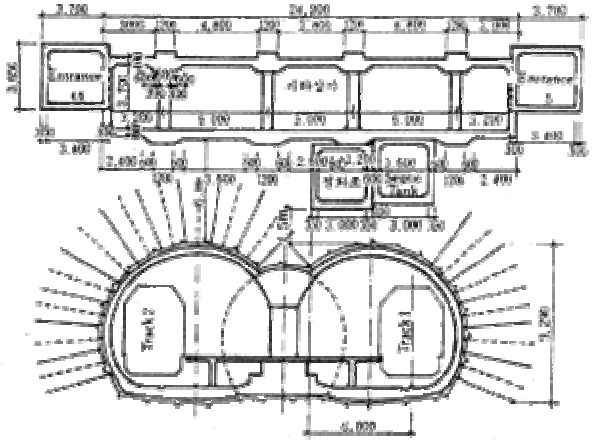


Figure 7. Cross section of Chungmu underground shopping area in Myeongdong station

2.5.4. Tunnelling at the 2nd phase of subway

For most of the tunnels in the 2nd phase subway construction, excavation patterns from Line 3 and Line 4 were applied. Additional auxiliary tunnel support methods such as jet grouting and mechanical excavation were adopted. Under-river tunnel between Yeoido and Mapo in Line 5 was constructed across the Han River.

As rock mass quality around Namsan and Chansin-dong area was very good (RQD up to 100%), tunnel stations with large cross sections were constructed. (Noksapyeong, Beotigogae and Changsin station) Rock support was also changed from conventional dry shotcrete into wet shotcrete with SFRS (Steel Fiber Reinforced Shotcrete) using robot-attached machine.

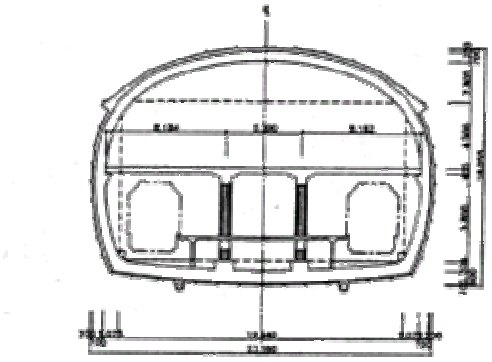


Figure 8. Cross section of Noksapyeong tunnel station

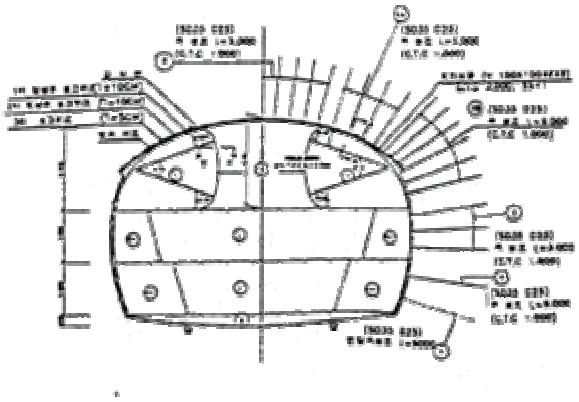
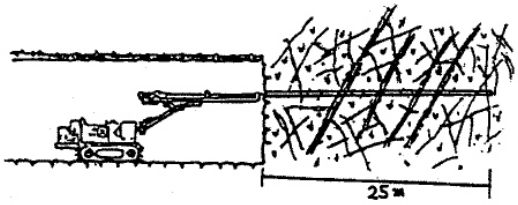
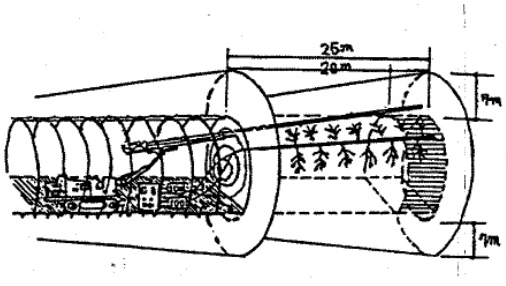


Figure 9. Rockbolt installation of Noksapyeong tunnel station

Advanced borehole investigation



LW grouting injection



Reinforced grouting umbrella

Excavation

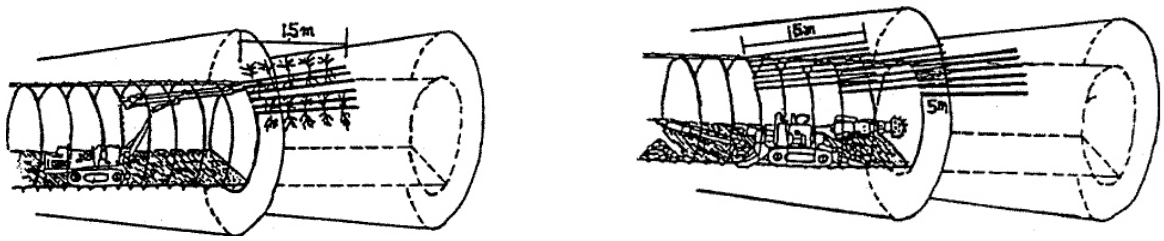


Figure 10. Tunnelling under the Han River

The first long under-river tunnel (length 1,288m), two single-track tunnels, was successfully constructed. Artificial Island was made in the middle of the Han River and used as a temporary access. Two emergency waterproof gates were installed to prevent seepage water diffusion and submergence of adjacent subway areas due to flooding by unexpected accidents. Several permanent geotechnical instruments were installed as well to measure displacement of the surrounding ground and lining due to the change of external forces such as groundwater table, earth pressure, overburden pressure and ground vibration. During construction, every measure was taken for the safe tunnelling.

- 1st step: Advanced borehole investigation
- 2nd step: Water retardation or waterproof (LW grouting)
- 3rd step: Reinforced pipe umbrella (φ=50mm, L=15m) grouting injection
- 4th step: Mechanical excavation application (Road Header, ITC etc.)

3. Legal system for subway development

3.1 National Land Planning and Utilizing Act (NLPUA)

Infrastructures such as road, railroad, subway, airport, and water supply system in urban area should be planned in accordance with NAPUL Article 20

- Drafting urban management plan (NAPUL Article 25)
  Urban management plan should be in accordance with regional urban planning and urban master plan. Documents on urban planning management plan and auxiliary-planning descriptions should be written when local governments draft urban management plans.

- Public hearing for residents and local council. (NAPUL Article 28)

Residents' opinions should be heard in the process of drafting urban management plans, and local government should adopt it if the opinions are recognized as reasonable. Opinions of local council also should be heard.

- Authorization of urban management plan (NAPUL Article 30)
  Mayors should consult relating administrative agencies on the contents of the draft, in advance, and Minister of Construction and Transportation (MOCT) should consult central governmental agencies on the draft. In this case, agencies should reply their opinions in 30 days. MOCT authorizes urban management plans based on the decision of Central Urban Planning Committee, and mayors authorize those plans according to the decision of Local Urban Planning Committee.

- Notice of topographic map (NAPUL Article 32)
  Authorized urban management plan should be specified on the topographic map that cadastral features are laid on. Authorized topographic maps are to be noticed and relating documents are to be open to public.

- Drafting execution plan and approval (NAPUL Article 88)
  Executors of construction projects of urban planning facilities should draw up 'execution plan' and get approvals. Execution plans should be open to public for more than 20 days, and the details are to be noticed

3.2. Urban Railroad Act

Railroad projects in urban areas are to be implemented in accordance with Urban Railroad Act (URA). This act aims at promoting the construction of subway to improve the traffic conditions in urban traffic zone, advancing urban transportation, and enhancing safety and convenience of passengers by rationalizing operation and managing equipments efficiently.

- Establishing master plan and authorization (URA Article 3-2, Ordinance Article 1-2)
  Mayors and governors of provinces, in case that construction and operation of urban railroad is required in transportation zone within their jurisdiction, should make up 'master plan' every 10 years and propose it to MOCT for authorization. To construct metro railroads not included in master plan, a corporation established for urban railroad projects on the basis of special act should consult mayors or governors of provinces and propose 'master plans for individual lines' to MOCT. MOCT should consult departments of central government on the 'master plan' and 'master plans for individual lines', authorize them according to the decision of Central Committee of Urban Transportation Policy, and notice them to public.

- Application for the license permit. (URA Article 4, Ordinance 4-2)
  Those who want to operate metro railroad construction businesses should get license from MOCT according to the article stipulated in Ordinance of URA. MOCT can give terms and conditions to the permissions of licenses of metro railroad construction businesses for the improvement of urban transportation and for the promotion of safety and convenience of passengers. Permitting licenses of metro railroad construction business, MOCT should issue licenses to applicants.

- Application for the license permit and issuing (URA Article 4-3)
  A licensee should get approval of the MOCT for the proposal of a project to construct and operate metro railroads within the scope of the 'master plan' and 'master plans for individual lines'. Public notice is required before requesting of project approval and relating documents should be opening to the public for more than 20 days. Approval of a project plan should be noticed on the official gazette.

3.3. Land ownership and acquisition

Land ownership rights reaches to upper and lower part of the land as far as its proper interests exist. (Civil Act Article 212) To utilize underground part of other person's land, the executer of railroad construction project should compensate the landowner referring to the use value of the land, depth from the surface, and negative effect on the land use. (URA Article 4-6)

Underground parts of other's land used for the purpose of constructing or protecting facilities of subway is liable for the underground compensation. Amount of compensation for the use of underground part of the land is to be estimated as reasonable price of the land (surface land projected to underground used part) multiplied by 'loss ratio of spatial use', which depends on the degree of decrease in the usefulness of the land caused by the installation of the subway facilities. Estimation standards of the spatial use value, use rate, etc are to be provided in the ordinances of local governments

The compensation regarding underground land use is laid down in Ordinance 2931 of the Seoul Metropolitan Government.

- Range of underground compensation (Article 4)
  Minimum range of occupied areas of underground facilities and areas for their maintenance. Plane range and spatial range are as follows. Plane range is the projected area of which the breadth is actual width of underground facility plus

minimum extra width and the length is the actual length of the underground facilities. Spatial range is the height from the bottom to the top of underground facilities plus thickness of protection layers that is 6m in case of tunnel structures and 0.5m for open cut structures.

- Determining the number of the most effective floors (Article5)
  Number of floors and scale under economical use, under considerations on land use status of neighboring lands, land price level, maturity, potentiality. Number of buildable floors depending on location, shape, and geology of the land.

- Calculating loss ratio of spatial use (Article7)
  Loss ratio of spatial use of land is a total sum of loss ratios of building use, underground use, and other uses.

  (Loss ratio of building use)
  - Loss ratio = $\alpha \times X/Y$

    α : loss ratio of building use

    X : ratio of use of floors at a loss

    Y : ratio of the most effective use of floors

  (Loss ratio of underground use)
  - Loss ratio = $\beta \times P$

    β : ratio of underground use

    P : efficiencies of underground use depending on the depth

  (Loss ratio of other uses)
  - Loss of both ground and underground use: v
  - Loss of either ground or underground use: v × sharing ratio

  (Loss ratio of spatial use)
  - Loss ratio of spatial use = loss ratio of building use and underground use as vacant land at its most effective condition × degree of aging + loss ratio of other uses
  - Degree of aging = age of building/lifetime of building

  (Critical depth)
  - High rise building area: 40m
  - Medium height building area: 35m
  - Low story building or residential area: 30m
  - Lands for agriculture or forest: 20m

4. Subway and urban development

4.1. Expansion of urban area

Subway is incomparably superior to other surface transportation systems in respect of rapidness, regularity, stability, etc. Once new subway line opens, rapid urban development occurs around station areas, for this reason. Transit oriented development based on improved accessibility results in rearrangement of population and industry and induces the population distribution and regionally balanced developments in metropolitan area. If average speed of urban surface transportation is 20~25 km/hr and commuting time is around a hour, then the radius and the area of urban living sphere may be 15~20 km and 700~1,200 km^2. But if 30~40 km/hr high speed commuting urban transportation like subway is constructed, urban living sphere can be expanded to 25~30 km radius and 2,000~3,000 km^2 area. This means that urban living sphere can be expanded 2~4 times if average speed of public transportation increases 1.5~2 times, and continuous urban development can be succeeding owing to the increase of the land supply for residential and business uses, overcoming the land shortage - one of the most tough problems in the metropolis.

The most significant urban problem of Seoul in 1960's ~1980's was caused by rapid urban sprawl. To study population of the Seoul city area, one can find that population has been explosively increasing that it was less than 2.5 million in 1960's, but 5.5 million in 1970's, 8 .35 million in 1980's, and 10.6 million in 1990's. Government has been driving population control policies that restrict new locations of universities and factories and promote moving them out of metropolitan area. To restrict population influx and induce distribution, Seoul tried to tie adjacent cities such as Incheon, Suwon, and Euijeongbu together into one living sphere by constructing subway Line 1, Keyongin Line, Kyeongsu Line, and Kyeongwon Line in 1974, and promoted to develop Kangnam in Seoul by constructing Line 2, 3, 4 by 1985. In addition, from 1990 to 2000, Gwacheon Line, Bundang Line, Ilsan Line as well as 2nd stage of Seoul subway lines and many new towns such as Seongnam, Goyang, Bucheon was constructed to expand urban spheres. By implementing a series of policies, population increase has been stopped since mid 1990's and got into stabilizing stage.

4.2. Balanced Development

Population tends to concentrate to city, pursuing the conveniences of living. The degree of concentration of population and urban functional facilities to CBD, sub centers, activity centers, and residential areas depends on the accessibility and convenience of transportation. Because the concentration of urban functions to small confined area actually creates many troubles such as traffic congestion and hardship of supplying urban spaces for residence and

business, the development should be regionally as balanced as possible although perfect interregional equality is impossible. Balanced development promotes residence and office getting close, enables daily activities to be performed within the local living spheres, reduces unnecessary traffic generations, supplies urban spaces for residence or business more cheaply, and utilizes limited land resources more efficiently.

For the balanced development of city, policies to improve accessibility, for instance, policies for even distribution of public transportation in entire city area should be executed. Convenient public transportation systems activate the new locations of urban functional units like retails and offices, and gradually develop sub centers and activity centers. Seoul is implementing urban policies aiming to transform spatial structures from single core CBD structure in 1970's, to 3-core (Yeongdeungpo, CBD, Youngdong, Jamsil) and sub center structure in 1980's, and to multi-core structure with 1 CBD, 4 living spheres, and 57 district centers at present. To lead balanced development, subway routes in Seoul were decided in accordance with those policies so that 3~5 lines are passing through CBD or sub centers, and 1~2 lines through every district centers.

4.3. Post-evaluation

After the completion of large scale construction projects, it is necessary to evaluate the influence of that project on the society and economy, the transformation of urban spatial structure that results from the change of the traffic system, and the extent of citizen's feelings as users on the influences. Although some scholars have partially researched in this post influence, actual achievement of the relating study on this issue has been poor due to the vastness of the scope of study and the limitation of systematic data gathering.

Nevertheless it is necessary to do post evaluation more actively for understanding the effect of the project, difficulties and improvements in executing the project, and for preventing trials and errors in succeeding projects. Seoul Metropolitan Government executed post evaluation on subway Line-5 construction project in 1998 after its completion, and central government also has been obliging to post evaluate for the projects of total cost above 50 billion won since 2000.

For subway construction works are long term projects with construction period from 3~4 years to 10 years, it is required to execute post evaluation on the project before, during, 5years after, and 10 years after the construction. In addition, geographical scope of the evaluation should include not only areas directly influenced by the stations and neighboring areas but also entire urban areas under indirect influence. Post evaluation currently done in Seoul

mainly is focused on the verification of the effect of the project and of the originally estimated cost and oblige to evaluate just once after completion of project, because it is early stage of introducing post evaluation system. To analyze mid or long term effect, it is necessary to evaluate more than twice, for example, 5 years and 10 years after completion of construction works.

To summarize the contents of post evaluation, it includes surveying actual and predicted indices of population and number of students in the entire area of city as well as adjacent areas of the subway lines and checking the number of passengers to examine the properness of execution plan. It analyzes and evaluates the influences of construction works on city by monitoring the change of population, land price, land use, number of employees and industries, variation of modal share, transition of traffic system by analyzing accessibility, change of air pollution and energy consumption for the station zone, non-station zone, transfer station, non-transfer station, etc respectively.

Evaluation of Line 5 completed in 1996 was done in 1998, and Line 7 completed in 2000 is currently being evaluated. Construction work of Line 5, very long route of 52.3 km with 50 stations, commenced in June 1990 and completed by 5 stages from 1994 to 1996. Currently, trains that consist of 8 cars run by 2.5 min interval at peak times and 5 min at normal times, and the number of passengers are 841 thousand per day. Subway Line 7, 46.9 km long and serviced by 42 stations connects residential areas to sub centers and links sub centers mutually. Construction works of Line 7 started in Dec. 1990 and completed in 3 stages by Aug. 2000. Currently, trains that consist of 8 cars run by 2.5 min interval at peak times and 5 min at normal times, and the number of passengers are 789 thousand per day.

Comparing of the population before the subway installation with after, a conclusion is derived that population in entire city area has been decreased but increased in the area along the subway route, especially large increase around the transfer station zones. It probably results from the high density development progressed around the station zone by getting the convenience of public transportation owing to the subway installation. Land and housing prices also more rapidly increased near station zones than other places, and the nearer a land located to the stations the more steeply the prices increase. Land use for a single family attached houses has decreased, while multi-family housing like apartment and retails increased, and the number of industries and employees tended to increase. Enhancement of accessibility helped land price increase, and as the high-density development progressed, industry and employment increased. An evaluation on the use status of the public transportation shows that modal share of the surface transportation such as buses and cars has rapidly decreased, while that of subway has highly increased. Affected by the change of the

energy use pattern. The consumption of light oil, gasoline, and LNG decreased more than 2%, and the discharge amount of air pollutants also reduced,

5. Lessons learned from Seoul subway development

5.1 Maintain Urban Functions by Subway Network

Subway system of Seoul plays a role of urban infrastructure, operating 287 km of 8 lines and undertaking 35% of total travels generated in a day. Subway of Seoul is firmly on the right track as an urban infrastructure in regard of accuracy and rapidness, making it impossible to think of transportation in Seoul without it. Citizens have a consensus that it is necessary to use subways to keep the important appointment time. Main facilities for meeting places are mostly located at station zone. An episode that happened a few years ago may clearly show the status of subway in Seoul as follows:

> *Once on a winter day in 2001, there was an unexpected snowfall heavy enough to paralyze the entire road transportation, and Seoul city government allowed to use subway out of charge. Thoughtful considerations of city, recommending giving up road transportation of personal vehicles and providing free use of subway for commuting, exited fresh impressions and pleasures of citizens. Although the subway was crowded and delayed more or less in the afternoon by jamming passengers, every citizen could return home safely.*

However rough the weather condition may be, rail transport like subway can operate and maintain urban functions under emergency situation such as labor strike and paralyzed surface transportation. Properly provided subway network maintains at least minimum urban function in any circumstances, activates city, and leads continuous advance.

5.2 Convenient Subway by Comprehensive Development Plan

Because Seoul's subway system has been developed individually and partially in the sequence of Line 1, 2, 3 and 4 in lack of comprehensive plan, distance for transfer between lines is long and transferring seems to be inconvenient. Although subway is very popular transportation means for ordinary people because citizens can use subway and transfer every lines by buying 1 ticket and the fare in city area is very cheap about 0.6 US$, it becomes the focus of criticism that transfer between lines is not easy and the distance is long.

Inconvenience of transfer is caused by the line-by-line constructions without a comprehensive subway plan for the entire city area. The locations of stations and facility placements in a station were not decided under a systematic connection to other lines that would be constructed later. It is actually difficult to make up the most idealistic transfer design for the existing subway lines, because hundred of thousand of people are using the lines everyday, while there is no other way to construct the transfer system together with the operation. Therefore, it is necessary to construct each subway lines based on the long-term comprehensive plan for the entire city area.

For this purpose, relating laws stipulate that mayors and governors of provinces should construct subway systems, line by line as needed, after the establishment of comprehensive subway construction plan of every 10 years. But because the laws also rules to fix entire investment plans all together with construction plans, local governments still make up construction plan for each lines separately due to the hardship of setting up long term fiscal plan and troublesomeness of long range network schematizing. Therefore, according to the spirits of laws, it is required to improve that long term plan deals with basic matters like general rules of network constitution, while more details such as financial investment plan, locations of stations, construction technique, etc. are to be presented in construction plan of each lines.

5.3 Role of Central Government in Continuing Subway Construction

Nobody can deny subways, as a main transportation means in the city, superior to any other public transportation that ever introduced, with respect to rapidness, accuracy, and comfortableness. Nevertheless, both policy makers and executors are somewhat reluctant to adopt subway policies readily. Subway construction demands vast amount of budgets, and also takes 5~6 years for each line to complete, while it takes long time to feel the returning effect of the construction. Financial resources are the most significant of all for subway construction. Once the subway construction work start, it is impossible to interrupt and vast amount of budgets should be supplied annually. Currently, decisions on subway construction projects are in charge of local governments for most of the countries or cities, and local governments also should prepare financial plans.

In Korea, subways are not being constructed satisfactorily, because mayors and governors of provinces establish financial plans as well as construction plans and have entire responsibilities for construction, while central government subsidizes a part of the construction cost. Therefore, to promote subway construction and to solve transportation problems in metropolis, it is necessary to readdress administration systems so that central

government can take more active role in supporting budgets for construction projects and in consulting on technical matters.

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