Chapter 7 Project Design

7.1 Alignment

7.1.1 Horizontal Alignment

(1) Basic Policy

The basic policy for the horizontal alignment design is as follows;

- In the eastern access to the 4th bridge, it is advantageous to put the alignment as far from the runway as possible considering the aerial limitations of Marcos A. Gelabert Airport; the horizontal alignment of the monorail is basically set on the east side of the access road to the 4th bridge and parallel to it.
- On the 4th bridge, the alignment runs on the south side of the bridge.
- In the western access to the 4th bridge,

  a) Before the crossing point with the Autopista;

  The alignment runs on the north side of the Panamericana since the road has no median and there are various buried pipelines on the south side of Panamericana from a fuel tank farm located at 9k500~11k000.

  b) After the crossing point with the Autopista;

  The monorail alignment runs in the center of the Panamericana since there is a 2~3m wide median in this section of the Panamericana.

(2) Conditions

The minimum horizontal curvature that is applied is shown in the Table below.

Table 7.1 Conditions for Horizontal Alignment

Location	Minimum horizontal curvature
Guide way	100m
Station	300m
Depot	50m

Source：JICA Study Team

In studying the horizontal alignment, a transition curve is applied between a straight section and a curve section with a required length that can be calculated from the formula indicated below.

$$L = \frac{V^3}{14R}$$

Where;
L: Length of transition curve (m)
R: Radius of curve（m）
V: Maximum speed of monorail (km/h)

7.1.2 Vertical Alignment

(1) Basic Policy

The basic policy for the vertical alignment study is as follows;

- An elevated structure is installed for the entire project route. Considering possible future road construction which will be crossing over the project route, a 5.5 m allowance is secured above the existing road surface. This allowance of 5.5m above the existing road surface is considered for flyovers crossing the route as well. A 2.0m vertical allowance is made for pedestrian bridges.

(2) Conditions

The conditions for the vertical alignment are shown in the table below;

Table 7.2 Conditions for Vertical Alignment

Item	Value
Max Gradient (Main track)	60‰
Max Gradient (Station)	10‰
Min Vertical Curve	1000m

Source：JICA Study Team

In areas where a slope section involves curvature, the maximum gradient is adjusted by applying the equivalent gradient that can be calculated by the following formula;

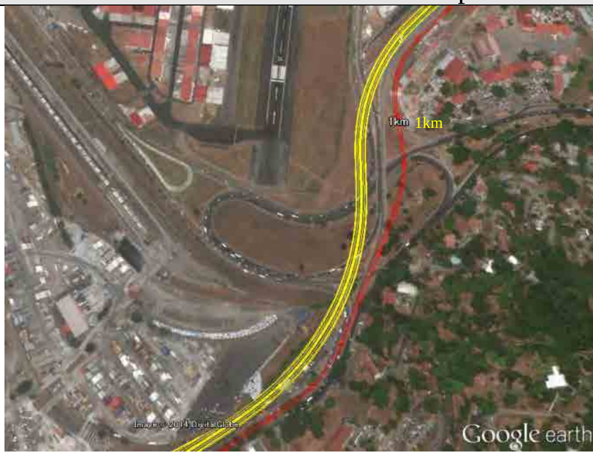
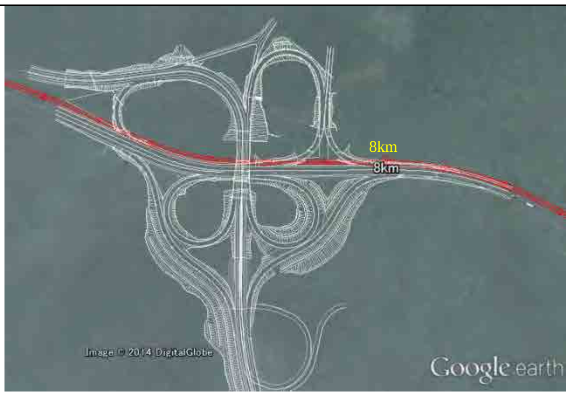
$$g = \frac{80}{R}$$

Where; g: Equivalent gradient against curvature (%)
R: Radius of curve（m）

7.1.3 Control Point

Major control points for the alignment design are summarized in the Table below. The preliminary alignment design is attached at the end of this report as an appendix.

Table 7.3 Major Control Points

Location	Description	
1k000m - 1k600m		It is essential to set the horizontal alignment as far from the runway of Marcos A. Gelabert Airport as possible in order not to violate the aerial limitation. In addition, monorail alignment has to be set so as to avoid the new intersection structures to be constructed in conjunction with the 4th Bridge.
1k600m - 2k200m		In the section along Roosevelt Ave, monorail structure shall be set low in the middle of existing median in order not to violate PAPI surface, which is the most critical aerial limitation. Alignment has to be set in between ACP's substation and chiller plant. It shall also avoid the access road to the 4th Bridge which will also be set in between ACP's facilities.
6k700m - 7k200m		Considering the accessibility to Panama Pacifico (PP), the PP station will be located on the south side of the Panamericana. Right after the PP station, the alignment has to pass over a road flyover. To avoid conflict with buried pipelines, the horizontal alignment shifts from the south to the north side of Panamericana after the PP station.
8km000 - 8km700		An interchange will be constructed between the Panamericana and the road from Panama Pacifico. The monorail structure has to be set high enough to cross over the structure of this interchange.

11km + 500 - 11km + 800		In order to secure the required length of the transition curve, the alignment has to diverge from the road to avoid consecutive curves. In preparation for the Loma Coba Station, the alignment shifts from north to south of the Panamericana.
12km + 200 Loma Coba St.		At the location of the Loma Coba Station, in order to secure the length of straight section necessary for a station, the alignment crosses over the Panamericana to avoid a conflict between the changing point of horizontal and vertical alignments.
14km + 300 - 14km + 700 Arraijan St.		Before the Arraijan Station, the alignment runs on the south side of the road. However, the alignment shifts from the south to the center of the road since a median appears right after the Arraijan St. and houses are built close to the road on the south side of the road.
All along the project route.		There are pedestrian bridges all along the Panamericana. The monorail's elevated structure shall pass over the existing pedestrian structures keeping sufficient clearance. However, in those locations where an existing pedestrian bridge coincides with a station, the pedestrian bridge will be removed.

Source：JICA Study Team

7.2 Rolling Stock

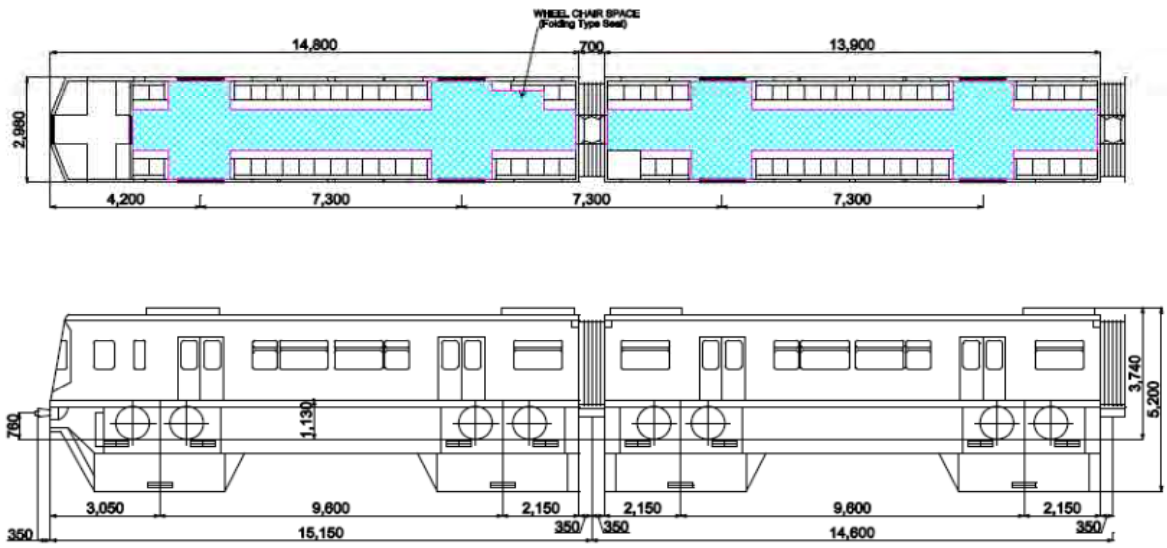
7.2.1 Transportation Capacity

As mentioned in Section 6.3 "Train Operation Plan", a 6-car straddle monorail has enough transport capacity to meet the demand calculated from the demand forecast. Therefore, a 6-car train shall be used from the commencement of operation, and it is also foreseen that this train formation will be able to cope with the future demand and will not need to be changed even in later phases.

(1) Seat Arrangement

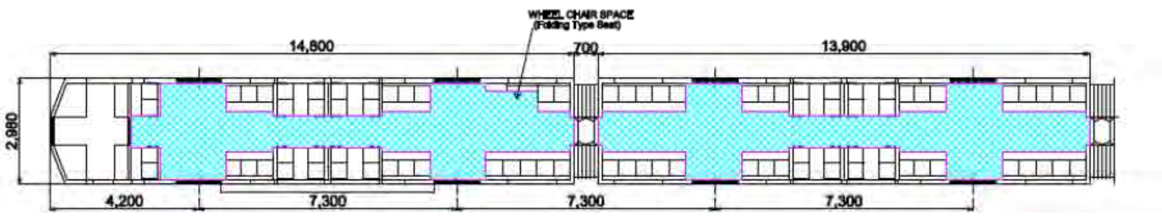
Figure 7.1 and Figure 7.2 illustrate examples of the car dimensions and the seat arrangement of a large-size straddle monorail.

Figure 7.1 shows the Long Seat Type Car which is composed of longitudinal seats only, with 246 seats in a train-set. Meanwhile, Figure 7.2 is an example of the Semi-cross Seat Type Car which has both longitudinal seats and traverse seats, with 270 seats in a train-set. Since Line-3 is characterized as a suburban transportation system due to its long distance between stations, the Study Team recommends that the Semi-cross Seat Type, which has more seats, be selected.



Source : JICA Study Team

Figure 7.1 Car Dimensions and Seat arrangement of "Long Seat Type"



Source : JICA Study Team

Figure 7.2 Seat arrangement of "Semi-cross Seat Type"

(2) Passenger Capacity and Car Weight

The following Table 7.4 and Table 7.5 show the results of calculating the transportation capacity and car weight. Table 7.4 is for the case of the Long Seat Type, and Table 7.5 is for the case of the Semi-cross Seat Type. The weight per person is set at 65 kg.

Table 7.4 Passenger Capacity and Car Weight (Long Seat Type)

Parameter			65 kg/ person				Train	
			End Car		Middle Car		(4M2T)	
Tare weight (t)			27.0		26.5		160.0	
Space for standees (m^2)			20.7		21.3		127	
Number of seats			35		44		246	
Condition	(person/ m²)		Person	Weight (t)	Person	Weight (t)	Person	Weight (t)
Tare	0	(AW0)	0	27.1	0	26.5	0	160
	0	(AW1)	35	29.4	44	29.4	246	176
Nominal	3		97	33.4	107	33.5	622	201
	4	(AW2)	117	34.7	129	34.9	750	209
	5		138	36.1	150	36.3	876	217
Fully loaded (1)	6	(AW3)	159	37.4	171	37.7	1,002	226
Fully loaded (2)	7		179	38.7	193	39.1	1,130	234
Fully loaded (3)	8	(AW4)	200	40.1	214	40.5	1,256	242
	9		221	41.5	235	41.8	1,382	250
Crush loaded	10	(AW5)	242	42.8	257	43.2	1,512	258

Source: JICA Study team

Table 7.5 Passenger Capacity and Car Weight (Semi-cross Seat Type)

Parameter			65 kg/ person				Train	
			End Car		Middle Car		(4M2T)	
Tare weight (t)			27.0		26.5		160.0	
Space for standees (m^2)			19.7		20.3		121	
Number of seats			39		48		270	
Condition	(person/ m²)		Person	Weight (t)	Person	Weight (t)	Person	Weight (t)
Tare	0	(AW0)	0	27.1	0	26.5	0	160
	0	(AW1)	39	29.6	48	29.7	270	178
Nominal	3		98	33.5	108	33.6	628	201
	4	(AW2)	117	34.7	129	34.9	750	209
	5		137	36.0	149	36.2	870	217
Full loaded (1)	6	(AW3)	157	37.3	169	37.5	990	225
Full loaded (2)	7		176	38.5	190	38.9	1,112	233
Full loaded (3)	8	(AW4)	196	39.8	210	40.2	1,232	240
	9		216	41.1	230	41.5	1,352	248
Crush loaded	10	(AW5)	236	42.4	251	42.9	1,476	256

Source: JICA Study team

The maximum permissible load for a monorails tire is 5.5 tons, so a large size monorail car can bear a maximum load of 44 tons. The above tables reveal that the gross car weight does not exceed the maximum load even under crush loaded condition (10 passenger/ m2).

It is noted that, in this study, the conditions of AW3 (6 passengers/ m2) and AW2 (4 passengers/ m2) at peak hour are applied in the selection of train transportation capacity for urban transportation and suburban transportation, respectively, in line with the standard practice.

7.2.2 Specifications of Rolling Stock

The specifications of rolling stock for Line 3 are described in Table 7.6.

These specifications are formulated with reference to the existing straddle monorail systems in Japan.

Numerical values related to vehicle performance are set tentatively, and can be changed in the detailed design phase.

The width of the passenger door is 1300 mm in accordance with the Japanese standard. Even if it is expanded to 1500 mm, the time for passenger alighting and boarding cannot be proportionately shortened, but the number of seats would be reduced. Furthermore, the western section of Line 3 needs to serve as a suburban transport system rather than an urban transport system. Therefore, alighting and boarding time is less important and thus the width of the passenger door is set at 1300 mm.

Table 7.6 Principal Specifications

Item	Specifications		
Car type	Tc	M	Train
Train Formation	6-car fixed formation: Tc-M-M-M-M-Tc		
Dimensions			
Car length	15.5 m	14.6 m	89.4 m
Car body length	14.8 m	13.9 m	-
Car width	2,980 mm	2,980 mm	2,980 mm
Car height (Max)	5,200 mm	5,200 mm	5,200 mm
Height above track surface	3,740 mm		
Floor height above track surface	1,130 mm		
Tare weight	27.0 t	26.5 t	160 t
Passengers capacity			
Numbers of seats	39 (35)	48 (44)	270 (246)
3 standees/m2	98 (97)	108 (107)	628 (622)
4 standees/m2	117 (117)	129 (129)	750 (750)
6 standees/m2	157 (159)	169 (171)	990 (1002)
Operation	Automatic Train Operation (ATO) with a train operator		
Performance	Maximum operation speed: 80 km/h		
	Acceleration: 3.5 km/h/s (0.97 m/s^2) at ATO mode		
	Deceleration: 3.5 km/h/s (0.97 m/s^2) at ATO mode		
	Maximum service deceleration: 4.0 km/h/s (1.11 m/s^2)		
	Maximum emergency deceleration: 4.5 km/h/s (1.25 m/s^2)		
	Maximum jerk rate: 0.75 m/s^3		
Minimum curve radius	Horizontal: 100 m at main line, 50 m at depot, Vertical: 1000 m		
Maximum gradient	60 ‰		
Car structure	Light alloy welding, fire-resistant		
Seat arrangement	Semi-cross seat type (or Long seat type)		
Door for passengers	2 doors / one side / car Opening width: 1300 mm, Opening height: 1850 mm		
Emergency door	1 door at center of cabin end		
Bogie	Biaxial, bolster-less, welded steel construction		
	Hydraulically driven disc brake		
	Running wheel: Tubeless rubber tire with Nitrogen gas		
	Guiding wheel and Stabilizing wheel: Rubber tire		
Traction power	DC 1500V		
Traction motor	Three phase squirrel-cage induction motor 110kW		
Traction control	VVVF inverter control (with regenerative brake) 2 traction motors / 1 controller		
Auxiliary power supply	Static Inverter 120 kVA		
Brake	Electric command electro-pneumatic brake with regenerative brake		
	Interlocked with ATP/ATO device, load compensating device		
Air condition Unit	Roof-Mounted type, 18.6 kW (16,000 kcal/ hour) x 2 / car		

Note: The data indicated in ( ) (brackets) are for Long seat type while data indicated without brackets are for Semi-cross seat type.
Source: JICA Study team

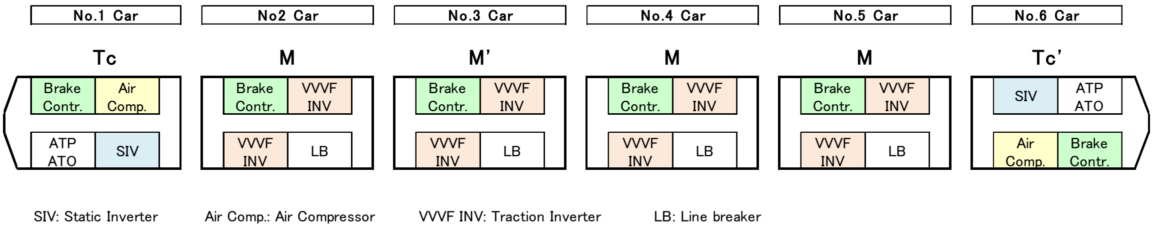
7.2.3 RAMS

(1) Standards and Criteria

Vehicles shall be designed and manufactured in accordance with international standards (IEC, EN, BS and JIS). Some provisions of these standards can be also used as guidelines for universal design.

(2) Redundant System Design

As shown in Figure 7.3, there are four intermediate motor cars. The main traction circuit is configured in a manner so that each car shall be controlled independently. One VVVF inverter controls two induction motors. If one inverter system is disabled, "High Acceleration Mode" is selected so that output from the active traction systems compensates the disabled traction capability as much as possible. The train is then driven at a higher traction capability than normal by the remaining traction system in order to minimize train delay.

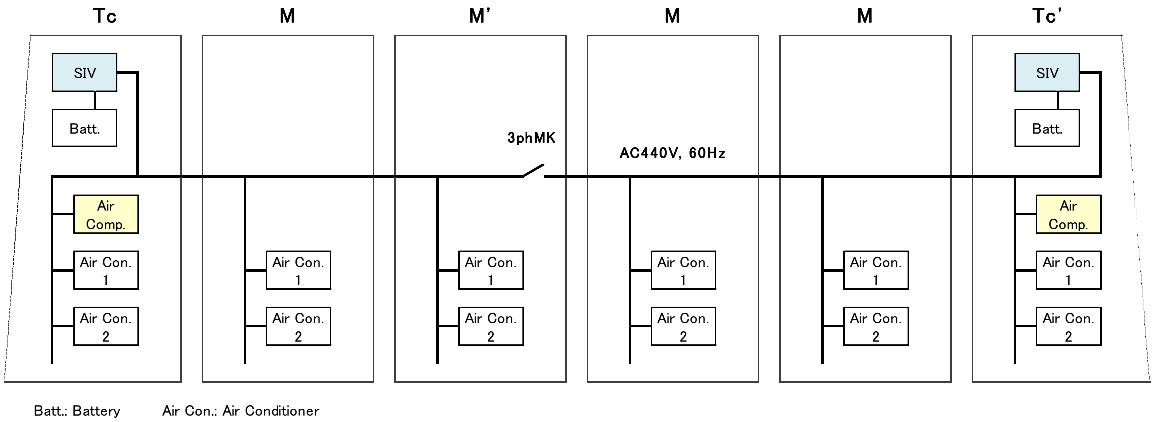


Source：JICA Study Team

Figure 7.3 Arrangement of Major Equipment

Under "High Acceleration Mode", a train can also be used to push or pull a disabled train to the nearest station even in the steepest section, which will prevent disabled trains from being stationary for a long time in the section between stations.

Regarding auxiliary systems, a static inverter (SIV), air compressor and battery circuit are designed redundantly for a train-set while two air conditioning units are equipped for each car as shown in Figure 7.4.



Source: JICA Study team

Figure 7.4 Auxiliary System

(3) Evacuation Methods in Emergency

In case that a monorail becomes immovable due to certain causes, another monorail nearby will rescue the passengers. If monorails near the stopped monorail are full with passengers, a monorail unloads passengers at the nearest station and goes to rescue the stopped monorail. An emergency door is installed at the front of the head car to enable passenger transfer to a rescue train.

The standards of National Fire Protection Association (NFPA) in USA were applied to Metro Line-1 construction project. According to NFPA-130, even a monorail system needs an emergency egress pathway, although there is no monorail system in Japan which adopts the standards because monorail cars are fireproof and incombustible. Walkways for emergency egress are not necessary in Line-3 Project with the anti-fire measurements described below. It was decided between SMP and the JICA Study Team that emergency egress pathways conforming to NFPA would not be necessary for Line-3.

(4) Anti-fire Measurements

Incombustible material or flame retardant material shall be used for the parts, equipment and facilities of the cars, even for textile material, in order to resist burning and prevent a fire from spreading.

In case a fire occurs, the method of train operation shall depend on the distance to the nearest station. If a fire is detected when a train is about to leave a station, it must be stopped immediately. If the fire is detected while a train running between stations, the train shall keep running and stop at the next station.

When a train cannot move between stations due to the simultaneous occurrence of a fire and power failure, first, fire extinguishers are used to put the fire out. Then, lighting and ventilation devices shall be activated by battery power and the passengers are kept inside train to wait for power recovery (for a maximum of 30 minutes). If the power recovery takes time, the emergency battery power system, which is proposed in the Study, will be operated.

Although some railway systems are equipped with pass-through doors to prevent fire spread, pass-through doors will not be used for Line-3 because it is rather better to enable easy movement to other cars if the anti-fire measurement mentioned above is applied.

(5) Speed at Curve Sections

The minimum curve radius is set to 100 m for the main line, and 50 m for the depot.

The speed in a curve section depends on the cant and the acceptable centrifugal force for passengers. Since a monorail has fewer derailments or overturns, the cant can, therefore, be higher than that applicable to MRT. The technical standard for Japanese monorails specifies the maximum cant as 12%, and cant deficiency is set at 5%, which is deemed as the deficiency that will not cause significantly uncomfortable feelings to passengers in train operation. In a depot where there are no passengers, cant deficiency can be increased to 7.5%.

Table 7.7 shows the calculation results of speed in curve sections.

(6) Maintenance

Apart from using rubber tires instead of steel wheels, a monorail uses parts and components that are similar to conventional MRT systems. Therefore, maintenance for a monorail is nearly the same as that for MRT system.

Table 7.7 Speed in Curve Section

Unit: km/h

R (m) \ Cd (%)	5					7.5				
Ca (%)	0	5	7.5	10	12	0	2	4	5	7.5
50	15	25	25	30	30	20	20	25	25	30
60	15	25	30	30	35	20	25	25	30	30
70	20	25	30	35	35	25	25	30	30	35
80	20	30	35	35	40	25	30	30	35	35
90	20	30	35	40	40	25	30	35	35	40
100	25	35	35	40	45	30	30	35	35	40
110	25	35	40	45	45	30	35	40	40	45
120	25	35	40	45	50	30	35	40	40	45
130	25	40	45	45	50	35	35	40	45	45
140	25	40	45	50	50	35	40	45	45	50
150	30	40	45	50	55	35	40	45	45	50
160	30	45	50	55	55	35	40	45	50	55
170	30	45	50	55	60	40	45	45	50	55
180	30	45	50	55	60	40	45	50	50	55
190	30	45	50	60	60	40	45	50	50	60
200	35	50	55	60	65	40	45	50	55	60
210	35	50	55	60	65	40	50	55	55	60
220	35	50	55	60	65	45	50	55	55	60
230	35	50	60	65	70	45	50	55	60	65
240	35	55	60	65	70	45	50	55	60	65
250	35	55	60	65	70	45	50	60	60	65
260	40	55	60	70	70	45	55	60	60	70
270	40	55	65	70	75	50	55	60	65	70
280	40	55	65	70	75	50	55	60	65	70
290	40	60	65	70	75	50	55	65	65	70
300	40	60	65	75	80	50	60	65	65	75
320	45	60	70	75	80	55	60	65	70	75
340	45	65	70	80	85	55	60	70	70	80
350	45	65	70	80	85	55	65	70	70	80
380	45	65	75	85	90	60	65	70	75	85
400	50	70	75	85	90	60	65	75	75	85
410	50	70	80	85	90	60	70	75	80	85

<u>**Equation**</u> Ve = 3.6*SQRT(9.807*R*(Ca+Cd)/100)
Ve = Equilibrium Cant Speed including cant deficiency (km/h)
R = Curve radius (m)
Ca = Actual cant (%) Cd = Cant deficiency (%)

Recommendation:

In a line composed of many curves, such as this Line 3, the maximum value (12% as shown in the above table) of Ca shall be used to increase the speed of a train in the curves and shorten total running time on the line. Nonetheless, in selecting the Cd, a large value (7.5% in the above table) shall be avoided in order to ensure ride comfort. The recommended Cd in this case is 5%.

In case a curve does not have enough actual cant, the speed should be reduced so as not to create a big centrifugal force from the car body to the bogie.

At small radius curves in the depot, a higher cant deficiency value may be applied because the mass of the car body is light with no passenger load.

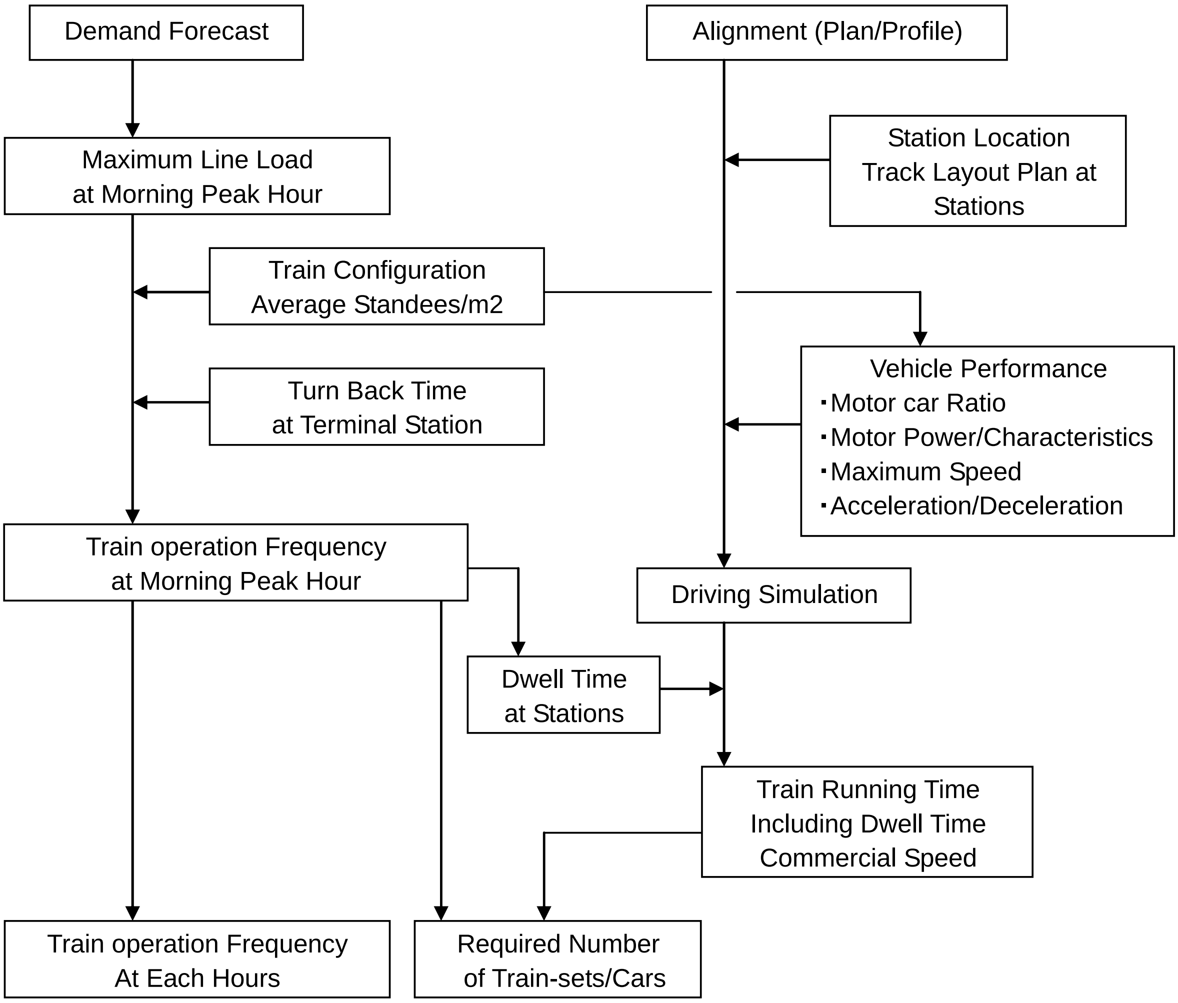
If there is great concern that the car may often stop on curves, the Ca should not have a large value. The recommended Ca is less than 5%.

Source: JICA Study team

7.3 Train Operation Plan

7.3.1 Methodology

As shown in Figure 7.5, the purpose of the train operation plan is for determining the required train frequency based on the peak hour peak direction traffic (PHPDT) obtained from the demand forecast. It also aims at analyzing train running time, commercial speed and the required number of train-sets/cars in consideration of the route alignment (plan/profile) and vehicle performance.



Source: JICA Study Team

Figure 7.5 Flowchart for Examining Train Operation

7.3.2 Preconditions of Examination

(1) Overall Preconditions

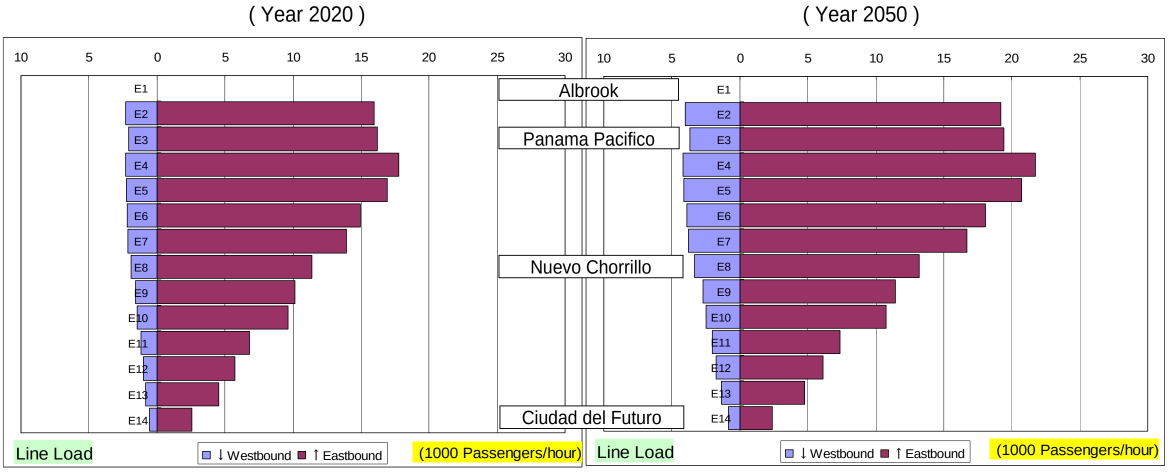
1) Target Year, Section for Examination, and Target Passenger Demand

This study focuses on the Phase 1 section of Line 3 (Albrook~Ciudad del Futuro), 25.8km, but the ultimate target demand is set at approx. 25,000 passengers per hour for Phase 2 (Albrook~La Chorrera) in 2050. In addition, the train operation has a transport capacity that could satisfy a certain amount of increase beyond this ultimate target demand.

2) Review of the Result of Demand Forecast

Figure 7.6 shows the PHPDT for each section between the stations in 2020 (assumed inauguration year of Phase 1) and in 2050 (the last year of demand forecast). In both cases, the PHPDT is highest in the section between Panama Pacifico (E3) and Loma Coba (E4), with approx. 18,000 passengers per hour in 2020 and approx. 22,000 passengers per hour in 2050 for eastbound trains (to Albrook).

Furthermore, the PHPDT increases station by station in the form of stairs as it approaches Panama Pacifico and is characteristic of a radial route that connects a city center with the suburbs. After stopping at Panama Pacifico, the PHPDT decreases slightly before reaching Albrook.



Source: JICA Study Team

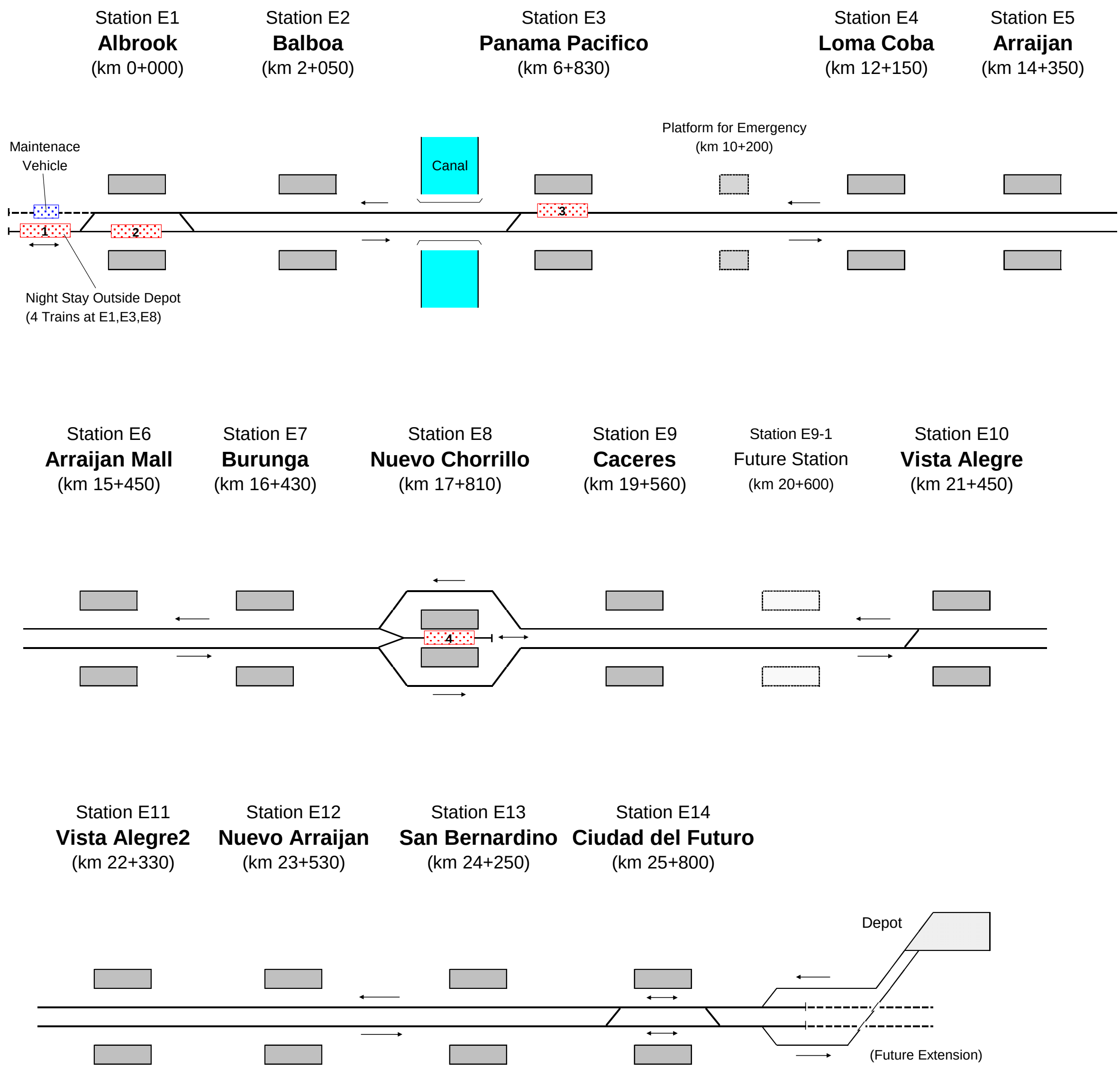
Figure 7.6 Passenger Line Load at Peak Hour in Phase 1

3) Track Layout Plan at Stations

Figure 7.7 illustrates the schematic track layout for the Phase 1 section of Line 3. The line is planned to be approx. 25.8km in length with 14 stations. Although the average distance between stations is approx. 2.0km, there is a significant difference between the east and west sections with Arraijan (E5) as the boundary. The average distance between stations is approx. 3.6 km in the east section (Albrook side) and approx. 1.3 km in the west section (Ciudad del Futuro side).

For the three turn-back stations, Albrook (E1), Nuevo Chorrillo (E8) and Ciudad del Futuro (E14), the track layout with turnouts and lead track is designed to enable monorail trains to turn back. The terminal station E14 is aligned to enable the future extension to La Chorrera. Furthermore, the length of the mountainous section between Panama Pacifico (E3) and Loma Coba (E4) is approx. 5.6 km which is longer than any other section. Therefore, simple emergency platforms shall be constructed between E3 and E4 to evacuate passengers to the ground in case of emergency. Also, a crossover is installed at E3 station.

In addition, an emergency crossover is installed at Vista Alegre (E10) to secure service operation in case of emergency.



Source: JICA Study Team

Figure 7.7 Track Layout Plan at Stations of Line 3 (Phase 1)

4) Train Configuration and Operation Performance

Table 7.8 demonstrates train configuration and operation performance. The train configuration adopts a 6-car train (including 4 motor cars) at the time of commencing operation, which remains unchanged even in the later phases. The reason for adopting a 6-car train from the commencement is that a 4-car train has insufficient transport capacity to meet the high demand volume estimated in the demand forecast. The analysis, proving that a 6-car train has sufficient transport capacity for the future, is described in the next section (2).

The maximum operation speed is set at 80 km/h, and both acceleration and deceleration rates are 3.5km/h/s.

Table 7.8 Train Configuration and Operation Performance

Item	Content
Train Configuration	6-car Train、4M2T（Tc-M-M-M-M-Tc）
Maximum Operation Speed	80km/h
Acceleration/Deceleration	3.5km/h/s (Both)

Source: JICA Study Team

(2) Study of Train Configuration and Average Number of Standees

The required train frequency at peak hour is calculated by dividing passenger volume at peak hour by train capacity. The train capacity can be calculated by the formula below. Since the number of seated passengers and the floor area for standees are determined by vehicle design, therefore, the remaining variables, such as the number of standees/m2, train configuration, and minimum headway need to be determined.

Table 7.9 shows the change of transport capacity under various combinations of headway (train frequency), train configuration and average number of standees. Colored values indicate a combination compatible with each targeted train capacity (to be discussed in the next section).

> Transport capacity per hour
>
> ＝｛Train capacity｝×｛Train frequency per hour｝
>
> ＝｛(number of seated passengers＋**average number of standees/m2**× floor area for standees)× **number of cars per train**｝×｛60 minutes／**minimum operation headway**｝

Table 7.9 Transport Capacity (PHPDT) of Monorail under Various Combinations

Average Standees /m2	Headway				150 sec	140 sec	130 sec	120 sec	110 sec	100 sec	90 sec
		5 min	4 min	3 min	2.5 min			2 min			1.5 min
	Frequency/hour	12	15	20	24	26	28	30	33	36	40
4 Standees	4car-train	5,904	7,380	9,840	11,808	12,792	13,776	14,760	16,236	17,712	19,680
	5car-train	7,452	9,315	12,420	14,904	16,146	17,388	18,630	20,493	22,356	24,840
	6car-train	9,000	11,250	15,000	18,000	19,500	21,000	22,500	24,750	27,000	30,000
	7car-train	10,548	13,185	17,580	21,096	22,854	24,612	26,370	29,007	31,644	35,160
	8car-train	12,096	15,120	20,160	24,192	26,208	28,224	30,240	33,264	36,288	40,320
5 Standees	4car-train	6,864	8,580	11,440	13,728	14,872	16,016	17,160	18,876	20,592	22,880
	5car-train	8,652	10,815	14,420	17,304	18,746	20,188	21,630	23,793	25,956	28,840
	6car-train	10,440	13,050	17,400	20,880	22,620	24,360	26,100	28,710	31,320	34,800
	7car-train	12,228	15,285	20,380	24,456	26,494	28,532	30,570	33,627	36,684	40,760
	8car-train	14,016	17,520	23,360	28,032	30,368	32,704	35,040	38,544	42,048	46,720
6 Standees	4car-train	7,824	9,780	13,040	15,648	16,952	18,256	19,560	21,516	23,472	26,080
	5car-train	9,852	12,315	16,420	19,704	21,346	22,988	24,630	27,093	29,556	32,840
	6car-train	11,880	14,850	19,800	23,760	25,740	27,720	29,700	32,670	35,640	39,600
	7car-train	13,908	17,385	23,180	27,816	30,134	32,452	34,770	38,247	41,724	46,360
	8car-train	15,936	19,920	26,560	31,872	34,528	37,184	39,840	43,824	47,808	53,120

(Note)
- (yellow) Can transport 25,000 passengers/hour as 2050 demand forecast result
- (green) Can transport 27,500 passengers/hour as 10% up of 2050 demand forecast result
- (blue) Can transport 30,000 passengers/hour as 20% up of 2050 demand forecast result

Source: JICA Study Team

In the demand forecast, the maximum passenger volume at peak hour is estimated to be approximately 25,000. However, it is necessary to allow a margin so that transport capacity can meet further increases resulting from the extension of the line to La Chorrera, the construction of new stations and urban development along the route in the future. Therefore, three scenarios of target passenger volume were studied, namely 25,000, 27,500 (up 10%), and 30,000 (up 20%) passengers. Table 7.10 shows the calculation result of the estimated average number of standees for the case of a 6-car train and a 7-car train, which are both suitable alternatives for the target passenger volume at minimum headway operation for all three scenarios.

The average number of standees for urban railways in general is 6 standees/m^2, but in this study the acceptable range was set at 4 standees/m^2 to provide less congested services.

In the case of 25,000 passengers, the average number of standees per area (m^2) is 4.04 for a 6-car train, and 3.79 for a 7-car train. In the case of 27,500 and 30,000 passengers, the average number of standees is 4.44~4.85 for a 6-car train, and 4.17~4.55 for a 7-car train. Thus, in all cases, the average number of standees is less than 5 standees/m^2.

If the passing speed over turnouts is improved and the turnout switching time is shortened (technologically feasible at present), a 6-car train can provide service with a minimum headway of 90 seconds. Than the 6-car train configuration would have the capacity to carry 30,000 passengers/hour.

To adopt a 7-car train, it would require the lengthening of the station platforms and the turn-back tracks, and expanding the depot and substations, which would result in either higher initial investment cost or O&M cost. In conclusion, this Study proposes a 6-car train configuration and an average standing density of 4~6 standees/m^2.

Table 7.10 Calculation of Assumed Average Standees for 3 Target Passenger Cases

Condition	Target Passengers to be Transported		Minimun Headway		Total Capacity PPHPD			Assumed Ave. Standees/m2
			sec	Frequency /hour	4Standees/m2	5Standees/m2	6Standees/m2	
6 -car Train	25,000	Result of Demand Forecast 2050	110	33	24,750	28,710	32,670	**4.04**
Present Condition	27,500	(Increased by 10%)						**4.44**
	30,000	(Increased by 20%)						**4.85**
7 -car Train	25,000	Result of Demand Forecast 2050	120	30	26,370	30,570	34,770	**3.79**
Present Condition	27,500	(Increased by 10%)						**4.17**
	30,000	(Increased by 20%)						**4.55**
6 -car Train	25,000	Result of Demand Forecast 2050	90	40	30,000	34,800	39,600	3.33
Improved Condition (Reference)	27,500	(Increased by 10%)						3.67
	30,000	(Increased by 20%)						4.00

Present Condition = Passing Speed at Crossover section 25km/h, Acceleration/Deceleration 3.0km/h/s, Switching Time 20sec
Improved Condition= Passing Speed at Crossover section 35km/h, Acceleration/Deceleration 3.5km/h/s, Switching Time 15sec
※Improved Conditions can be actually introduced technically.

Source: JICA Study Team

(3) Advanced Opening during Construction Period

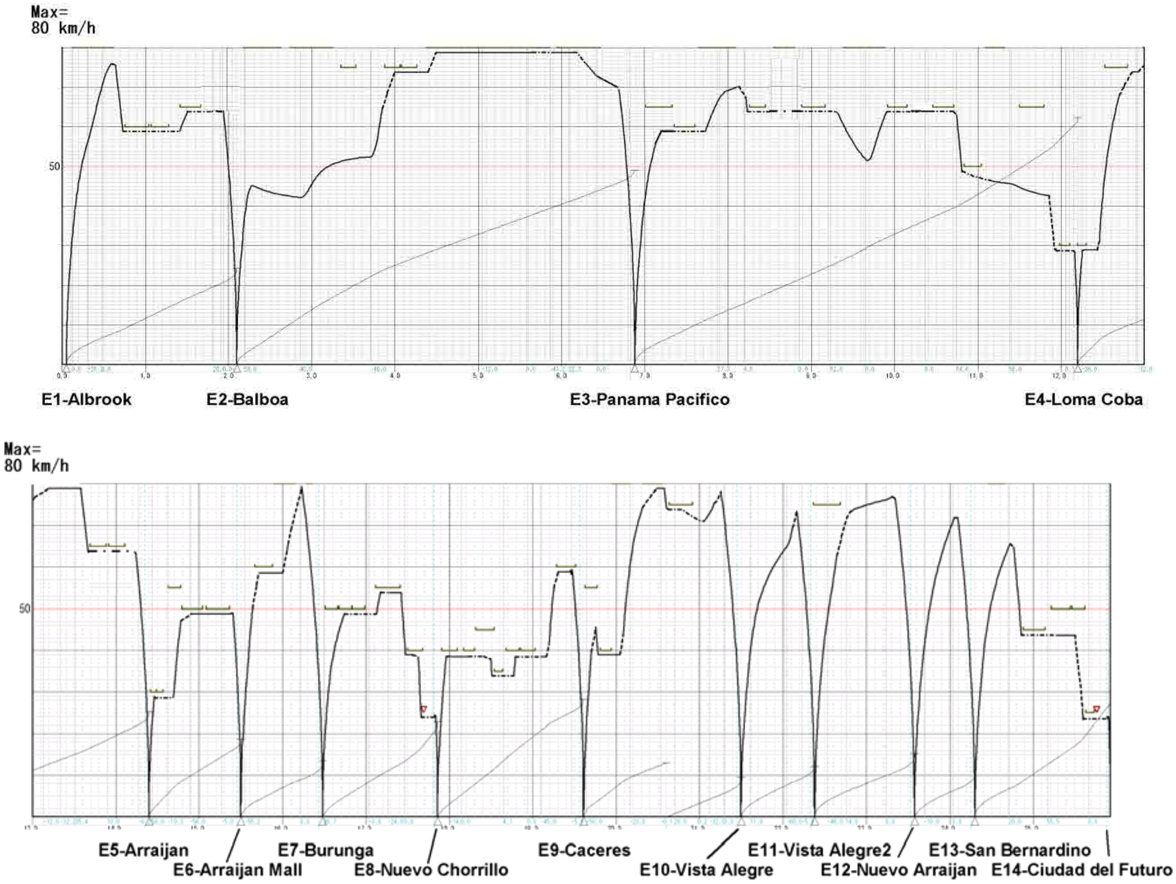
During the Study, the section of Phase 1 was assumed to be opened at once on completion of the 4th Panama Canal Bridge. However, in the consultation meeting of Draft Final Report, it was proposed that the section to the west of Panama Pacifico be opened 6 months prior to the opening of the entire Phase 1 section, and the construction plan was modified according to the schedule.

Since the original plan included a test run of the section to the west of Panama Pacifico, there is no issue to open the section prior to the entire Phase -1 section. However, to make the operation plan of the section, it is necessary to clarify the condition of the demand forecast, fare system, connection with buses, and so on. Since the Study did not include such analysis, it should be studied in the next stage.

7.3.3 Train Running Simulation

(1) Preparation of the Train Run-Curve

Figure 7.8 shows the train run-curve drawn by the Running Curve Simulator based on the examined alignment (plan, profile and station location) and train performance.



Source: JICA Study Team

Figure 7.8 Train Run-Curve of Line 3 (Phase 1)

(2) Required Train Operation Time and Commercial Speed

Table 7.11 shows the result of the examination.

The required train running time for the whole route is 39 minutes 50 seconds including dwell time at the intermediate stations (30 seconds as a standard), 25 minutes 20 seconds in the east section (Albrook - Nuevo Chorrillo), and 14 minutes 30 seconds in the west section (Nuevo Chorrillo - Ciudad del Futuro).

The commercial speed is 38.9 km/h for the whole route, 42.2km/h in the east section, and 33.1km/h in the west section. The speed in the east section is approx. 9km/h faster than the speed in the west section due to the longer distance between stations.

In addition, three stations of E6(Arraijan Mall), E9(Caceres) and E13(San Bernardino) will be considered to install several years after the commencement of commercial operation. In this simulation, the calculation is done as three stations are installed simultaneously in 2025.

Table 7.11 Required Train Operation Time and Commercial Speed (After 2025)

	Section Length (km)	Average Distance between Stations (km)	Train Operation Time (min:sec)			Commercial Speed (km/h)
			Running Time	Dwell Time	Total	
Whole Route (E1-E14)	25.80	2.0	33:50	6:00	39:50	38.9
East Section (E1-E8)	17.81	2.5	21:50	3:30	25:20	42.2
West Section (E8-E14)	7.99	1.3	12:00	2:30	14:30	33.1

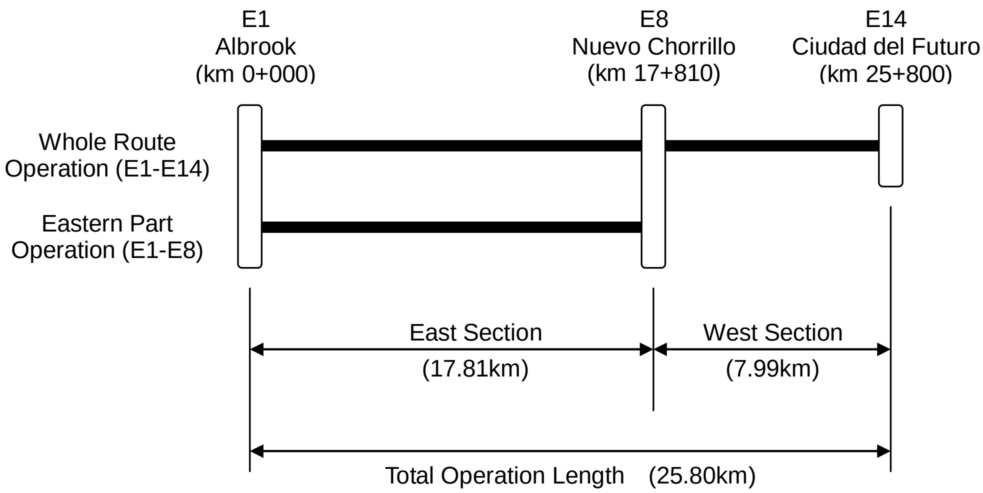
Note:
1. The travel time for each interval between stations is rounded up to 5 seconds from simulation results.
2. Dwell time is set at 30 seconds as a standard, but it is set at 50 seconds at E1 where many passengers alight at the morning peak hour with reference to examples of Japanese subway. (Dwell time at E1 is excluded from the calculation of commercial speed because Albrook station is the final stop.)
3. Station No. E1 is Albrook, E8 is Nuevo Chorrillo, and E14 is Ciudad del Futuro.
Source: JICA Study Team

7.3.4 Train Operation Plan

(1) Train Operation Pattern

As mentioned above, the demand forecast reveals that the PHPDT increases station by station in the shape of stairs and that there is a comparatively large difference in passengers at the section between Nuevo Chorrillo (E8) and Arraijan Mall (E6). Therefore, to appropriately cope with this tendency and implement efficient train operation, this study recommends that a part of the fleet departing from Albrook station turn back at Nuevo Chorrillo station. The reason for setting Nuevo Chorrillo as a turn back station is that there are residences concentrated around this station making it suitable as a turn back station.

For the above-mentioned reasons, two operation patterns shall be planned, namely "Whole Route Operation" and "Eastern Part Operation" as shown in Figure 7.9.



Source: JICA Study Team

Figure 7.9 Train Operation Patterns of Line 3 (Phase 1)

(2) Train Operation Plan at Peak Hour

Train frequency at peak hour is calculated by dividing the PHPDT (for six cases: 2020, 2025, 2030, 2035, 2040, and 2050), based on the demand forecast, by the train capacity (990 passengers/train). Train capacity can be obtained from train configuration (6-car train) and the average number of standees (6 standees/m2 as a standard and 4 standees/m2 in the less congested west section).

As the result of this calculation, in the east section, the train frequency is 18 trains per hour (3.33 minutes headway) in 2020, and 22 trains per hour (2.73 minutes headway) in 2050. Meanwhile, in the west section, the number is 11 trains per hour (5.45 minutes headway) in 2020, and 12 trains per hour (5 minutes headway) in 2050.

Table 7.12 Calculation of Train Operation Plan at Peak Hour (East and West Section)

Section	Item	Unit	Formula \ Year	2020	2025	2030	2035	2040	2050	Remarks
East Section (E1-E8)	Peak Demand per Hour	Persons/Hour･Direction	a1	17,763	18,757	19,440	20,060	20,604	21,766	Between E4 and E3 (Eastbound Train)
	Train Composition *1	Cars/Train	b1	6	6	6	6	6	6	
	Target Standees/m2	Persons/m2	c1	6	6	6	6	6	6	
	Train Capacity *1	Persons/Train	d1	990	990	990	990	990	990	
	Required Train Operation Frequency	Trains/Hour･Direction	e1=a1/d1	18	19	20	21	21	22	
	Set Train Operation Frequency	Trains/Hour･Direction	f1	18	19	20	21	21	22	
	Train Operation Headway	min.	g1=60/f1	3.33	3.16	3.00	2.86	2.86	2.73	
	Calculated Standees/m2	Persons/m2	h1	5.95	5.95	5.82	5.69	5.90	5.97	Between E5 and E1 higher than 5.0
West Section (E8-E14)	Peak Demand per Hour	Persons/Hour･Direction	a2	10,136	10,631	10,789	10,957	11,069	11,423	Between E9 and E8 (Eastbound Train)
	Train Composition *1	Cars/Train	b2=b1	6	6	6	6	6	6	
	Target Standees/m2	Persons/m2	c2=c1	6	6	6	6	6	6	
	Train Capacity *1	Persons/Train	d2=d1	990	990	990	990	990	990	
	Required Train Operation Frequency	Trains/Hour･Direction	e2=a2/d2	11	11	11	12	12	12	
	Set Train Operation Frequency	Trains/Hour･Direction	f2	11	11	11	12	12	12	
	Train Operation Headway	min.	g2=60/f2	5.45	5.45	5.45	5.00	5.00	5.00	
	Calculated Standees/m2	Persons/m2	h2	5.41	5.78	5.90	5.34	5.41	5.66	Between E10 and E8 higher than 4.0

Notice(*1): 6car-Train=Tc-M-M-M-M-Tc
Car Capacity (persons Tc/M) 4 Standees/m2=117/129, 5 Standees/m2=137/149, 6 Standees/m2=157/169

Source: JICA Study Team

(3) Calculation of the required Number of Train-sets/Cars

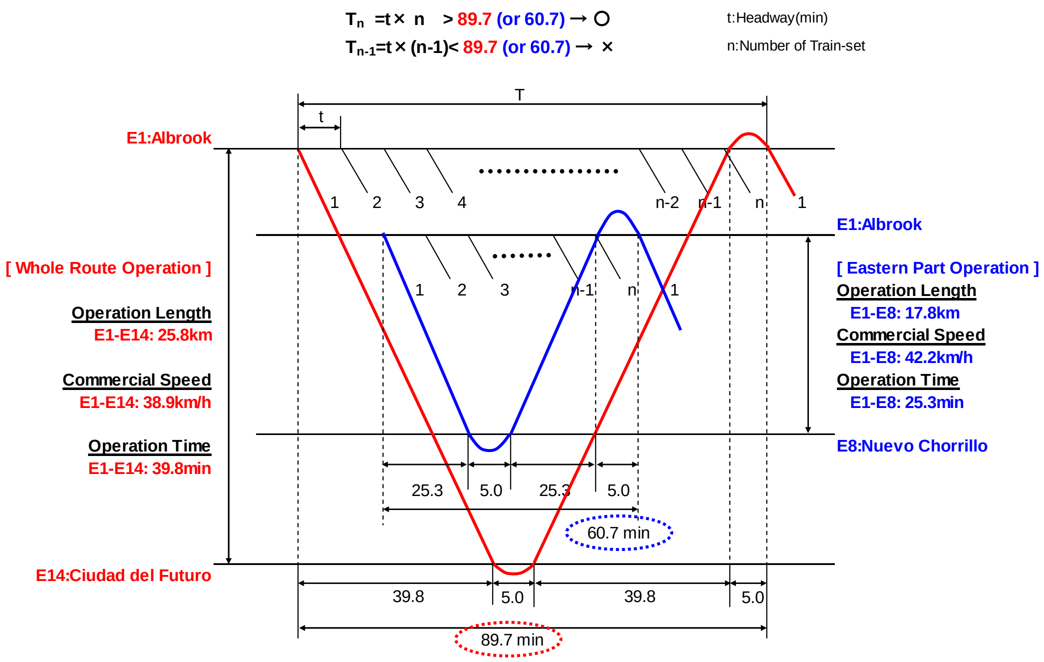
1) Method of Calculation

The required number of cars is calculated from the round-trip time at peak hour. For this line, two operation patterns are planned, namely the Whole Route Operation and the Eastern Part Operation. Therefore, as described in Source: JICA Study Team

Figure 7.10, first, the round-trip time for each operation pattern is calculated. The result is divided by the corresponding headway of each operation pattern, and then the number of spare train-sets (3 train-sets) is added. The final result is the required number of train-sets.

2) Result of Calculation

As a result of the calculation made by the above method, the required number of train-sets and cars is 26 train-sets (156 cars) in 2020 (not commenced E6, E9 and E13), 29 train-sets (174 cars) in 2025 (commenced all 14 stations), and 32 train-sets (192 cars) in 2050, as shown in Table 7.13. Because transport demand is high in year 2020, a relatively large number of cars is necessary from the commencement of train services.



Source: JICA Study Team

Figure 7.10 Calculation Method of the Required Train-sets at Peak Hour

Table 7.13 Calculation Result of the required Number of Train-sets/Cars

Operation Pattern	Item	Unit	Formula \ Year	2020	2025	2030	2035	2040	2050
Whole Route Operation (E1-E14) (25.80km)	Operation Length (1 Direction)	km/Direction	a1	25.80	25.80	25.80	25.80	25.80	25.80
	Train Operation Frequency	Trains/Hour･Direction	b1	11	11	11	12	12	12
	Train Operation Headway	min.	c1=60/b1	5.45	5.45	5.45	5.00	5.00	5.00
	Roundtrip Time	min.	d1	84.5	89.7	89.7	89.7	89.7	89.7
	Number of Trains for Operation	Trains	e1=d1/c1	16	17	17	18	18	18
Eastern Part Operation (E1-E8) (17.81km)	Operation Length (1 Direction)	km/Direction	a2	17.81	17.81	17.81	17.81	17.81	17.81
	Train Operation Frequency	Trains/Hour･Direction	b2	7	8	9	9	9	10
	Train Operation Headway	min.	c2=60/b2	8.57	7.50	6.67	6.67	6.67	6.00
	Roundtrip Time	min.	d2	59.2	60.7	60.7	60.7	60.7	60.7
	Number of Trains for Operation	Trains	e2=d2/c2	7	9	10	10	10	11
Total Number of Trains/Cars	for Operation	Trains	e=e1+e2	23	26	27	28	28	29
	for Spare	Trains	f	3	3	3	3	3	3
	Total Number (Trains)	Trains	g=e+f	26	29	30	31	31	32
	Train Composition	Cars/Train	h	6	6	6	6	6	6
	Total Number (Cars)	Cars	i=g*h	156	174	180	186	186	192

Note: 1.Number of Spare Train-sets are set to 3, each 1 Train-set for sudden breakdown, monthly inspection, and overhoul or renewal.
2.Stations E6, E9 and E13 will be commenced in 2025. Train running time (including dwell time) before 2024 will be shorter than after 2025 by 2min35sec for whole route and 45sec for eastern part.

Source: JICA Study Team

(4) Train Operation Frequency for the Whole Day

Train operation frequency for the whole day is computed in Table 7.14 based on train frequency at the morning peak hour (6:00-7:00) and operation of cars.

Commercial operating hours are from 5 a.m. to 24 p.m. (19 hours), and the total train-trips of the two operation patterns for the whole day per direction is 211 trains in 2020, and 244 trains in 2050.

Table 7.14 Train Operation Frequency/Headway of a Whole Day (2020-2050)

Year	2020				2025				2030				2035				2040				2050			
Item	Train Operation Frequency (trains/hour/direction)			Total Headway (min)	Train Operation Frequency (trains/hour/direction)			Total Headway (min)	Train Operation Frequency (trains/hour/direction)			Total Headway (min)	Train Operation Frequency (trains/hour/direction)			Total Headway (min)	Train Operation Frequency (trains/hour/direction)			Total Headway (min)	Train Operation Frequency (trains/hour/direction)			Total Headway (min)
Hour	Whole Route (E1-E14)	Eastern Part (E1-E8)	Total		Whole Route (E1-E14)	Eastern Part (E1-E8)	Total		Whole Route (E1-E14)	Eastern Part (E1-E8)	Total		Whole Route (E1-E14)	Eastern Part (E1-E8)	Total		Whole Route (E1-E14)	Eastern Part (E1-E8)	Total		Whole Route (E1-E14)	Eastern Part (E1-E8)	Total	
5-6	9	5	14	4.29	9	5	14	4.29	9	6	15	4.00	9	6	15	4.00	9	6	15	4.00	10	6	16	3.75
6-7	11	7	18	3.33	11	8	19	3.16	11	9	20	3.00	12	9	21	2.86	12	9	21	2.86	12	10	22	2.73
7-8	9	5	14	4.29	9	5	14	4.29	9	6	15	4.00	9	6	15	4.00	9	6	15	4.00	10	6	16	3.75
8-9	9	5	14	4.29	9	5	14	4.29	9	6	15	4.00	9	6	15	4.00	9	6	15	4.00	10	6	16	3.75
9-10	6	3	9	6.67	6	3	9	6.67	6	4	10	6.00	6	4	10	6.00	6	4	10	6.00	6	5	11	5.45
10-11	6	3	9	6.67	6	3	9	6.67	6	4	10	6.00	6	4	10	6.00	6	4	10	6.00	6	5	11	5.45
11-12	6	3	9	6.67	6	3	9	6.67	6	4	10	6.00	6	4	10	6.00	6	4	10	6.00	6	5	11	5.45
12-13	6	3	9	6.67	6	3	9	6.67	6	4	10	6.00	6	4	10	6.00	6	4	10	6.00	6	5	11	5.45
13-14	6	3	9	6.67	6	3	9	6.67	6	4	10	6.00	6	4	10	6.00	6	4	10	6.00	6	5	11	5.45
14-15	6	3	9	6.67	6	3	9	6.67	6	4	10	6.00	6	4	10	6.00	6	4	10	6.00	6	5	11	5.45
15-16	8	4	12	5.00	8	4	12	5.00	8	4	12	5.00	8	4	12	5.00	8	4	12	5.00	8	5	13	4.62
16-17	8	4	12	5.00	8	4	12	5.00	8	4	12	5.00	8	4	12	5.00	8	4	12	5.00	8	5	13	4.62
17-18	9	5	14	4.29	9	5	14	4.29	9	6	15	4.00	9	6	15	4.00	9	6	15	4.00	10	6	16	3.75
18-19	9	5	14	4.29	9	5	14	4.29	9	6	15	4.00	9	6	15	4.00	9	6	15	4.00	10	6	16	3.75
19-20	8	4	12	5.00	8	4	12	5.00	8	4	12	5.00	8	4	12	5.00	8	4	12	5.00	8	5	13	4.62
20-21	8	4	12	5.00	8	4	12	5.00	8	4	12	5.00	8	4	12	5.00	8	4	12	5.00	8	5	13	4.62
21-22	6	3	9	6.67	6	3	9	6.67	6	4	10	6.00	6	4	10	6.00	6	4	10	6.00	6	5	11	5.45
22-23	5	2	7	8.57	5	2	7	8.57	5	3	8	7.50	5	3	8	7.50	5	3	8	7.50	5	3	8	7.50
23-24	4	1	5	12.00	4	1	5	12.00	4	1	5	12.00	4	1	5	12.00	4	1	5	12.00	4	1	5	12.00
TOTAL	139	72	211		139	73	212		139	87	226		140	87	227		140	87	227		145	99	244	

Grounds of Basic Design: 5- 6 (Starting/Morning Transition) = Average of Morning Peak and Daytime
6- 7 (Morning Peak) = Transport Peak Demand by Suitable Frequency (within Target Standees/m2)
7- 9 (Morning Transition) = Average of Morning Peak and Daytime
9-15 (Daytime) = Half of Morning Peak
15-17 (Evening Transition) = Average of Daytime and Evening Peak
17-19 (Evening Peak) = Same to Morning Transition
19-21 (Evening Transition) = Average of Daytime and Evening Peak
21-22 (Night Time) = Same to Daytime
22-23 (Late Night) = Average of Night Time and Midnight
23-24 (Midnight) = Indispensable Service Level (Every 10-20 min.)

Notice: 1.In calculation of train operation frequency, headway will be rounded for the purpose of easy understanding for passengers.
2.Train operation frequency in each service hour may increase depending on actual rostering requirements.

Source: JICA Study Team

7.4 Civil Structure

7.4.1 Basic policy

- In general, the design shall be in accordance with ASTM, AASHTO and JIS standards
- Panamanian standards should be taken into account where applicable
- The design shall provide access-friendly stations for all users
- The design shall have an attractive appearance for users and society

7.4.2 Applicable Design Standards

(1) Geometric Design

- MLIT - Structure design standard for urban monorail

(2) Geo Technical Investigation

- ASTM D1586 - Soil Standard Penetration Test SPT
- AASHTO M145 – Soil sampling and classification test method

(3) Earthworks

- AASHTO T 27 - Maximum particle size
- AASHTO T 90 - Plasticity Index
- AASHTO T 180 - Density Moisture Relationship
- AASHTO T 193 - Laboratory CBR
- AASHTO T 193 - Penetration test
- AASHTO T 191 - Field Moisture Content
- AASHTO T 191 - Field Density

(4) Foundations

- ASTM D1143- Piles, Static load
- ASTM C-39 Compressive Strength Tests on cylinders
- Cements for structural concrete works shall be Portland cements which comply with JIS R 5210, ASTM C 150, AASHTO M 85 or equivalent and Portland Cement Type I which complies with ASTM C150 or equivalent
- ASTM D4945 Dynamic load test for piles method

(5) Concrete Structure

The materials and workmanship used in the manufacture of concrete shall be in accordance with JIS A 1101, ASTM C 143, AASHTO T 119, JIS A 1108, ASTM C 39, ASSHTO T 22, ACI 214, JIS A 1132, ASTM C 31, AASHTO T 23, JIS A 1105, ASTM C 87, AASHTO T 71, ASTM C-150, ASTM C-1077, ASTM -94 C and ASTM C-33 or approved equivalent international standards as appropriate for concrete works, and as modified by this Specification.

(6) Steel Structure

Steel reinforcement used in structural concrete shall conform with the requirements of JIS G 3112, ASTM A615, AASHTO M 31, and ACI 408.1 R.

(7) Fire Prevention

There is a Panamanian norm for fire prevention which is called "Reglamento de las Oficinas de Seguridad para La Prevención de Incendios de La Republica de Panamá" (Regulation of Safety Offices of the Republic of Panama for Fire Prevention). This is complemented by NFPA 130 of US Standard because the Panamanian regulation stipulates very basic issues only.

(8) Barrier free design

In the Republic of Panama, the "Decreto Ejecutivo N°88 de 12 de noviembre de 2002", whereby Law N°42 of August 27, 1999 is regulated, establishes the equalization of opportunities for people with disabilities, establishes the parameters, design standards and minimum requirements applicable to constructions, expansion works or recommendations for buildings, parks, pavements, gardens, roads, sanitary services or other spaces intended for public use.

7.5 Guideway Structures

7.5.1 Super Structure

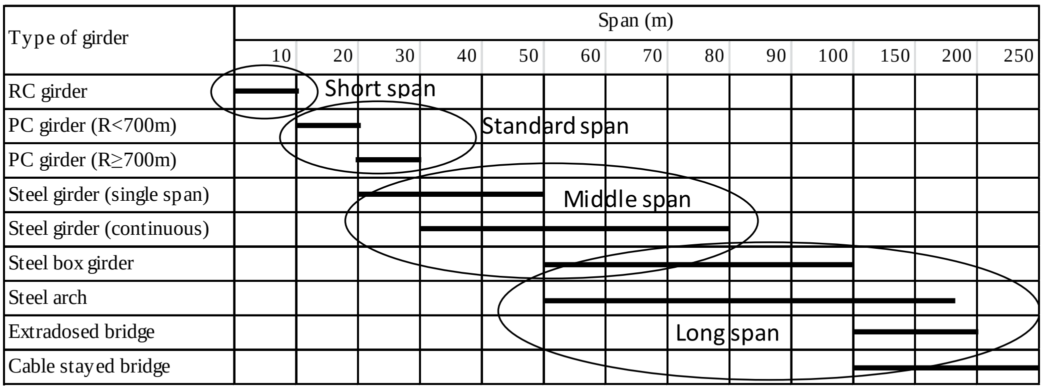
Monorail girders are classified in the following four types. The appropriate girder structure for each span type will be selected as per following figure.

1) Short Span (Span length: ~10m): Reinforced concrete girder

2) Standard Span (Span length: 22~30m): Pre-stressed concrete girder

3) Middle Span (Span length: 30m~80m): Steel Girder Bridge

4) Long Span (Span length: 80m~): Steel Arch Bridge and etc.



Source: JICA Study Team

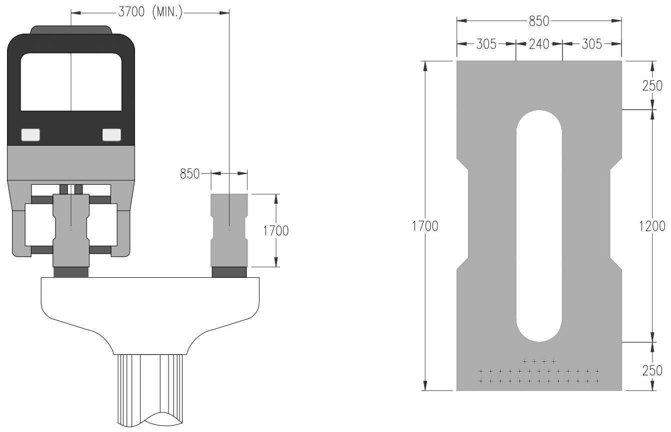
Figure 7.11 Selection of superstructure type

1) Short Span (Span length: ~10m): Reinforced concrete girder

The reinforced concrete girder will be applied to the tracks in the storage line in the depot and the span length will be less than 10m.

2) Standard Span (Span length: 10~30m): Pre-stressed concrete girder

For the standard pre-stressed concrete girder, single span and continuous span girders are possible. In the case of the single span girder, the maximum span length will be 25 m as a standard. The girder will be pre-cast at a factory, transported to the erection point and launched on bearings. In the case of the continuous span girder, the span length will be extended up to approximately 30m because of structural advantage. However, at the construction stage, reinforcement-bar arrangement, formwork and concrete pouring between the girders at site are required and the construction period might be longer than for the single span girder.

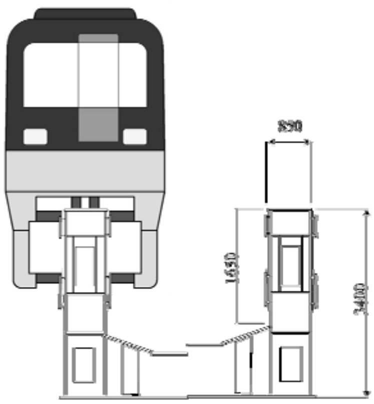


Source: JICA Study Team

Figure 7.12 Cross Section of pre-stressed concrete girder (L=25m)

3) Middle Span (Span length: 30m~80m): Steel Girder Bridge

Steel girders are applied for crossing points over roads where the span length will be 30m~80m, in case the standard pre-stressed concrete girder cannot be applied.



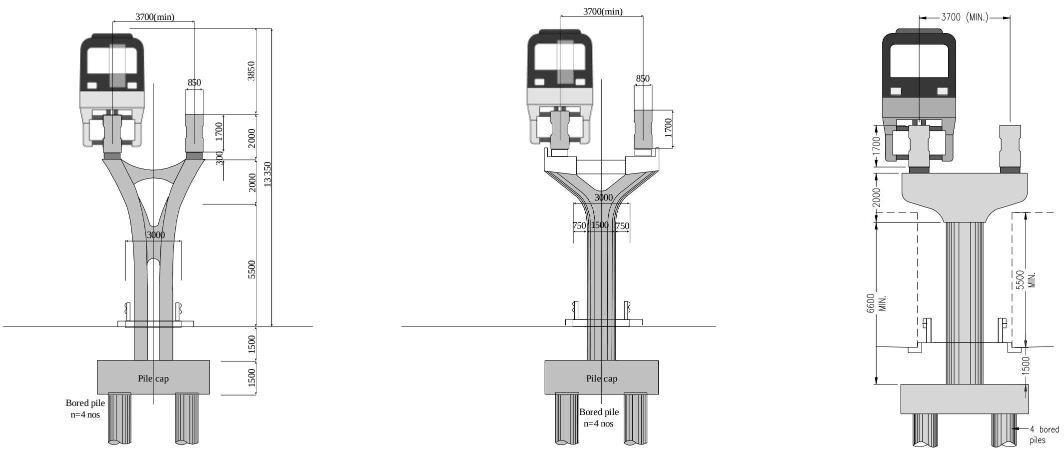
Source: JICA Study Team

Figure 7.13 Cross Section of Steel Girder Bridge (L=50m)

4) Long Span (Span length: 80m~): Steel Arch Bridge, etc.

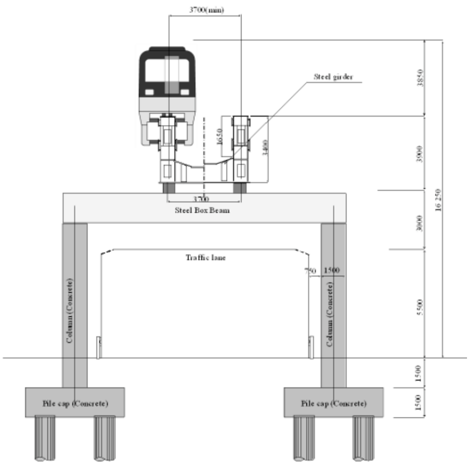
7.5.2 Substructures

The structural requirement of monorail columns, depending on the height, is approximately 1.40m to 2.15m diameter in the case of circular piers, which are easily accommodated in the central median of the road. The shape of the piers is to be designed to follow the flow of forces. For tall/ slender pier columns, a higher strength concrete is to be used. The pier cap is shaped in a manner that it will provide a minimum vertical clearance of 5.5 m over the finished road surface. The pier cap is sized to accommodate the pedestals supporting the bearings. Space for jacks for lifting the girders is planned between the bearing pedestals. For the draining of water, the top of the pier cap will be sloping outwards with a slope of 1:200. Elevated monorail systems do not occupy any space on the road surface except for the abovementioned columns. Typical cross sections of monorail piers are shown in Figure 7.14 and Figure 7.15.



Source: JICA Study Team

Figure 7.14 Typical Cross Section of Monorail Piers



Source: JICA Study Team

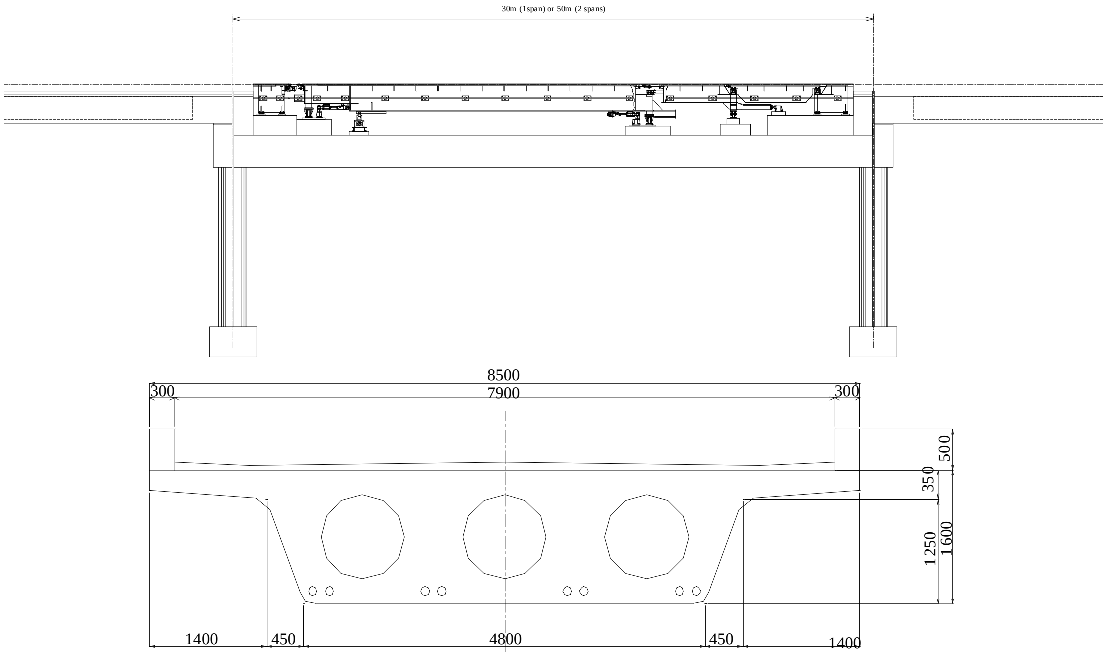
Figure 7.15 Typical Cross Section of a Monorail Viaduct Portal Type Pier

7.5.3 Foundation

To decide on the type of foundation and its depth, a geotechnical survey was carried out along the route alignment. It is expected that all structures will need to be supported by pile foundation. The depth of the bearing layer from the ground level is expected to be from 10m to 30m as shown in Chapter 5. The proposal is to provide 1000/1200/1500 mm dia. bored cast in situ vertical piles. A pile cap approximately 1.4 to 1.8 m thick will be cast over the piles. The pile cap will be kept a minimum of 1500mm below the road level or ground level.

7.5.4 Switch Bridges

Switches and their equipment are installed on the switch bridges. Pre-stressed concrete slab structure shall be applied for the switch bridge.



Source: JICA Study Team

Figure 7.16 Profile and Cross Section of a Monorail switch bridge

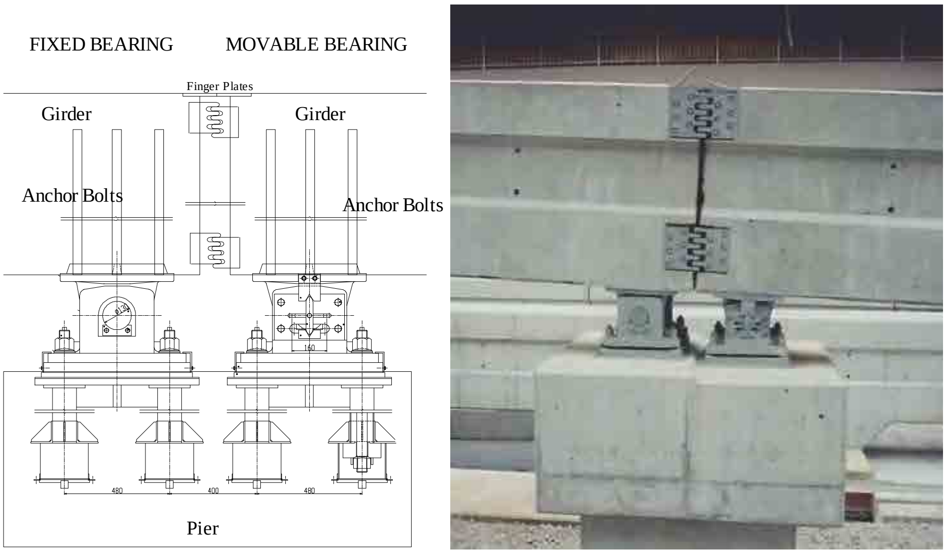
7.5.5 Other facilities on the track

(1) Anti-slip surface on the girder

To prevent the tires from slipping on the surface of the steel girder, usage of steel plates with grooves or slip resistance coating will be applied. A steel plate with grooves increases friction between the rubber tire and the surface of the girder by making grooves on the surface, while slip resistance coating increases the friction by coating epoxy resin mortar with silica sand.

(2) Bearing system and expansion joints

The bearing system for the non-continuous track beam will be resistant to vertical, horizontal and torsional reactions. Moreover, it will work smoothly against movement due to temperature differences and angular movement due to live load. The bearing design will be suitable for easy future replacement of track girders and will be adjustable for girder positioning. To provide for a smooth and comfortable ride, steel finger joints will be applied at the ends of the girders.



Source: JICA Study Team

Figure 7.17 Bearings and Expansion Joints (Example)

(3) Stoppers

At the end of the last girder of the line, stoppers on the beam/ pier shall be installed to prevent over-run accidents.

Source: JICA Study Team

Figure 7.18 Photo of the stoppers, (Sample: end of Tama Monorail)

7.5.6 Design Loads

(1) Design Specifications

Specifications for the structural design shall conform to those approved by MOP for the standard design of bridges in Panama. The main design specifications to use for the structural design are presented below:

- American Association of State Highway and Transportation Officials, AASHTO LRFD Bridge Design Specifications, Third Edition, 2004.
- American Concrete Institute, ACI-318.
- American Institute of Steel Construction, AISC.
- Seismic Code for the Republic of Panama, "Reglamento de Diseño Estructural de La

República de Panamá” (Regulation of Structural Design of the Republic of Panama).

The design method will be according to AASHTO LRFD, but there are some special specifications that will be added as follows:

- The live loads are not specified in AASHTO so the distribution and axle loads axles will be according to that of a monorail, as presented later in this document.
- The seismic design will follow AASHTO LRFD and, in order to incorporate the seismic conditions of the site, the value of the ground acceleration coefficient (A) will be taken from the seismic zoning of the Panama Code.
- Additionally, the load combinations will not be taken from AASHTO, but will be specified especially for the supporting structure design of a monorail. The load combinations and coefficients for allowable stress for the project are shown in Table 7.15.

(2) Design Loads

The following loads shall be considered for the analysis of the superstructure.

Primary loads:	Secondary loads:
a) Dead load (D) b) Live load (L) c) Impact load (I) d) Pre-stressed force (PS) [if required] e) Influence of Creep of Concrete (CR) [if required] f) Influence of Dryness/Shrink of Concrete (SH) [if required] g) Centrifugal force (CF) h) Earth pressure (E) [if required] i) Water pressure (HP) [if required] j) Buoyancy (U) [if required] k) Influence of Support Down (SD) [if required] l) Force to Handrail (HF) [if required] m) Transversal live load effect (LF)	a) Longitudinal live load effects (BK) b) Wind load (W) c) Overall temperature variation d) Seismic effect e) Collision force (CO) [if required] f) Erection force (ER) [if required] g) Friction of Bearing (F) [if required] h) Buffer stop effect (ST) [if required]

Table 7.15 Design load combinations

	Load cases												a
		D	L	I	LF	CF	T	W	BK	EQ	ER	ST	
Load Combinations	1	O	O	O	O	O							1.00
	2	O	O	O		O	O						1.15
	3	O	O	O		O		O					1.25
	4	O	O	O		O			O				1.25
	5	O	O	O		O		O	O			O	1.35
	6	O	O										1.60
	7	O						O					1.25
	8	O	O			O	O			O			1.60
	9										O		1.25

Source: JICA Study Team based on MLIT Monorail Structure Standards

The transversal live load should be considered because the monorail's load is submitted to the girder not only through running wheels for vertical direction but also through guiding load for horizontal direction. The transversal live load exerts a force on the top of the girder for the perpendicular to the direction of monorail.

(3) Dead Load

Typical dead loads for the project are as follows:

- Reinforced concrete: 2,400 kg/m³
- Structural steel: 7,800 kg/m³
- Soil (backfill): 1,500 – 1,800 kg/m³

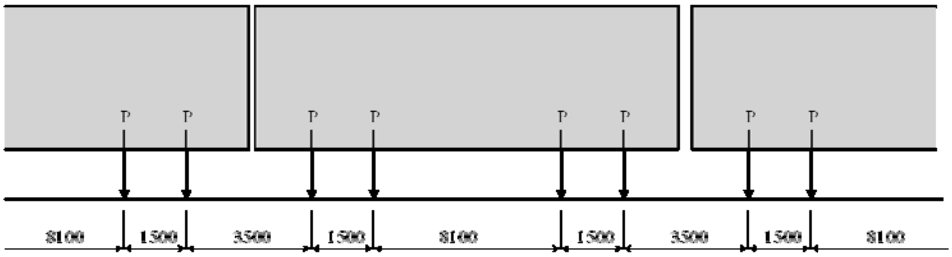
(4) Live Load

The live load to be used for the project corresponds to a large straddle type monorail, "Tc" and "M". The load consists of a 6-car train (Tc-M-M-M-M-Tc).

(5) Vertical Effects of Live Load

The axle arrangement and the axle loads to be used for the design are presented on Table 7.16 and Figure 7.19.

Axle arrangement is shown in the figure below.



Source: JICA Study Team

Figure 7.19 Axle arrangement

Table 7.16 Axle Loads

Description	P(tons)	Calculation	Source
Crush load	11.0	= 44.0/4	Table 7.4
Nominal load	9.0	= 35.2/4	
Tare	7.0	= 27.6/4	

Source: JICA Study Team

For the calculation of centrifugal and braking forces, the center of gravity of the monorail is taken as 1300 mm measured from the top of the superstructure (see Figure 7.20). The centrifugal and braking forces are horizontal and are taken as a fraction of the vertical live load, as presented in AASHTO LRFD.

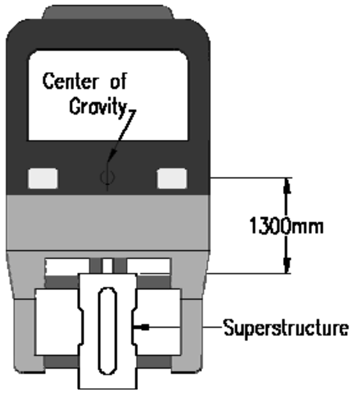


Figure 7.20 Center of gravity of the Monorail

(6) Seismic Load

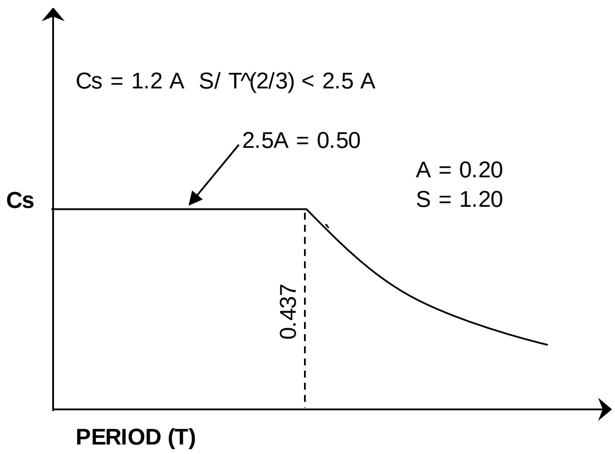
As mentioned before, the seismic design will follow the methodology of AASHTO LRFD. The value of the coefficient of ground acceleration, A, will be taken from the seismic code of Panama; this value has a minimum of 0.15g and a maximum of 0.20g.

The lateral seismic load is obtained by multiplying the dead load of the superstructure by a response coefficient factor. The seismic coefficient is calculated from the following formula from AASHTO LRFD:

$$Cs = 1.2\ A\ S/\ T^{(2/3)} < 2.5\ A$$

Cs: Response Coefficient.
A: Coefficient of Ground Acceleration, from Seismic Zoning of Panama.
S: Site Effects from Type of Soil Classification of AASHTO LRFD.
T: Structure Period.

The method of analysis for the calculation of the period of the structure to be used is the Multimode Elastic Method, taken from AASHTO. When the period is obtained the Response Coefficient is calculated from the Response Spectrum shown below.



T (seg)	Cs	Use
0.100	1.338	0.500
0.437	0.500	0.500
0.500	0.457	0.457
0.700	0.365	0.365
0.900	0.309	0.309
1.000	0.288	0.288
1.100	0.270	0.270
1.300	0.242	0.242
1.500	0.220	0.220
1.700	0.202	0.202
1.900	0.188	0.188

Source: JICA Study Team

Figure 7.21 Response Spectrum

Depending on the height of the columns periods of 0.90 to 1.80 seconds and seismic coefficients of 0.31 to 0.20 are obtained from preliminary calculations.

7.6 Station

7.6.1 Station equipment

Necessary functions and equipment for a standard station of Line-3 are evaluated as shown in the table below.

Station Equipment	Application Policy to Line-3
1) Ticket window	Tickets are sold at ticket offices by station staff. The size of the ticket window to be constructed will be sufficient to accommodate an automatic ticket vending machine in the future.
2) Ticket gate	Ticket gates are installed. Ticket gates will have a width of 90cm in order to allow passengers in wheelchairs or with large bags to pass through easily.
3) Station office and ticket room	A station office is installed near the entrance for station staff to work, take a rest or for standby personnel. Next to the station office is a ticket room containing both the ticket window and passenger information displays. However, at small stations a minimum sized ticket room will be installed only for the purpose of selling tickets and providing passenger information.
4) Electric and mechanical (E&M) room and signaling and telecommunication equipment (S&C) room	An electric and mechanical (E&M) room and signaling and telecommunication equipment (S&C) room are installed at the concourse level. The E&M room contains electrical equipment to distribute electric power to station facilities and lighting. The S&C room contains signaling and telecommunication equipment.
5) Rest room	Although rest rooms are not installed in Line-1's stations, rest rooms shall be installed in major stations only in case of Line-3.
6) Ascending facilities (Elevator and Escalator)	In addition to stairs, elevators and escalators shall be installed on all types of platform.
7) Platform screen door	Platform screen doors with a height of 1.20m or more will need to be installed at the edge of the platform in order to prevent passenger falls.
8) Air conditioner and Ventilation	Not installed for the platforms
9) Substation facilities	Substations will be installed at some of the stations at the concourse level.
10) Security System	CCVT will be installed to monitor the stations.

7.6.2 Station Geometry

The dimensions of the stations for the monorail system will be determined by train length and passenger volume, and the dimensions will be arranged to take into consideration passenger convenience.

The design policy of the stations is as follows:

(1) For passenger convenience, barrier free design and universal design shall be applied;

(2) A simple structure shall be applied emphasizing the monorail's characteristics and utilizing natural air ventilation; and

(3) Land acquisition shall be minimized by placing the monorail, as much as possible, in the central part of the existing road.

The required spaces for the stations are as follows.

(1) The minimum length of a platform will need to include the train length plus 10 meters of margin. For Line-3 a 6-car train with a length of 90m is used, thus the minimum platform length would be 100m;

(2) The effective width of a platform will be estimated on the basis of the expected passenger volume from the transport demand forecast. A minimum width of 3 m should be secured for passenger circulation; and

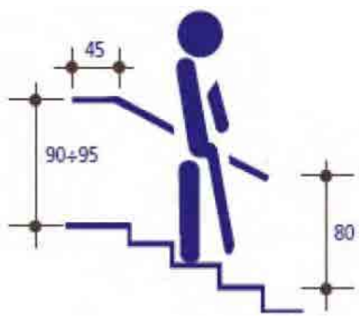
(3) A 6 m distance is required from the outside of a station building to allow for firefighting activity in the vicinity of the station. It is desirable to allow a gap of 10 m or more between the outside wall of the stations and the nearest buildings in order to avoid the feeling of oppression from the presence of the station building over a road in the densely urbanized sections.

7.6.3 Barrier free and universal design

(1) Barrier free standards in Panamá

In Panama, the "Practical Guide for Accessibility" needs to be followed for the design. An example of the considerations that need to be taken are shown in Figure 7.22.

Construction of ramps



Construction of hand rails

Source: Practical Guide for Accessibility

Figure 7.22 Standards for Equilibrium Control

(2) Comparison of standards

Table 7.17 shows the summarized comparison of barrier free standards between Panama and Japan which also has advanced standards of barrier free design.

Table 7.17 Comparison of Barrier free standards

Item	Standards in Panamá	Standards in Japan
1.Law and Guideline	Law: Decreto Ejecutivo N° 88 de 12 de Noviembre de 2002 Whereby Law N° 42 of August 27, 1999 is regulated, which establishes the Equalization of Opportunities for People with Disabilities.	Law: Law on Promotion of Smooth Transportation, etc. of Elderly Persons, Disabled Persons, etc. (2006, Japan) Guidelines to improve public transport passenger facilities for smooth transportation (2013, Japan)
2. General	Buildings and all public spaces shall be designed to be accessible and practical for users with reduced mobility or other disabilities. Access conditions, use, orientation, safety and functionality shall be taken into consideration.	All public spaces shall be designed in accordance with the above mentioned Law and Guideline.
3. Passage way	Detailed in Article 34 of the Regulation of Law N° 42 of 1999. - Access ramp minimum width shall be of 1.5 m. - Continuous double handrails must be placed on both sides of an access ramp. These shall be placed at both 70 cm and 90 cm height. - Anti-slip floor. - Optimum circulation slope of 8%.	Slopes and passageways are specified in the Guideline. • Minimum width: 1.2m • Hand rail shall be installed. In case of double hand rail, the height must be approximately 65cm and 85cm. • Anti-slip floor • Slope should be 1/12 or more.
4. Toilet	Design for toilets is appropriately specified in Article 35 of the Regulation of Law N° 42 of 1999.	Designs for Toilets are specified in the Guidelines.
5. Signboards	Detailed in the Accessibility manual of "Desarrollo de la Normativa Nacional de Accesibilidad en temas de Urbanística y Arquitectura" (Development of National Regulations for Accessibility in matters of Urban Planning and Architecture) of January 2012.	Signboards are specified in Guidelines.
6. Platform of the stations	Specified appropriately in Article 49 of the Regulation of Law N° 42 of 1999. In stations that feature a height difference between the platform and the vehicle, it is compulsory to provide the necessary equipment for entry and exit of passengers with reduced mobility, particularly wheelchair users.	The gap between train and platform shall be minimized and the elevation shall be flat. In order to avoid accident, Platform Screen Doors (PSD) shall be installed for station platform if available.
7. Voice information and Notification Display	Detailed in Article 47 of the Regulation of Law N° 42 of 1999. Information systems regarding routes, next stops, current stops shall be incorporated. These should be transmitted for visually or hearing impaired passengers.	Voice announcement services and Notification Displays in the train and station are recommended.
8. Tactile ground surface indicators	Continuous guilds (handrail, stripe texture, sound) are required for blind persons.	Tactile ground surface indicators must be installed along the path between the entrance from public passage and the boarding and alighting place through the toll gates.
8. Elevator	- Elevator signs and buttons shall be placed between 80 -140 cm. - Signs and buttons must be complete with embossed text along with information and instructions in Braille.	-The buttons have to be set within the reach of wheel chair passengers. - Voice information for blind passengers is recommended.

	- Elevators should have voice messages/information.	
9. Escalator	Appropriately specified in Article 51 of the Regulation of Law N° 42 of 1999. At the start and end of the escalator, raised cladding in a contrasting color to the steps will be incorporated.	The edge of the step shall be clearly distinguishable.
10. Facility layout map of the station	-	At the main entrance and/or near the ticket gate, facility layout map of the station shall be displayed.

Source: JICA Study Team based on Panamanian and Japanese regulations

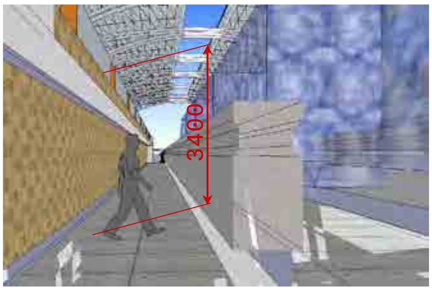
(3) Standards to be applied for the station design

The JICA Study Team recommends that some items from the Japanese standards be referred to in order to improve the accessibility of the monorail stations.

(4) Recommendations

1) Platform Screen Doors

In Japan, the installation of platform doors to prevent accidents is recommended. Because the gap between the platform level and the slab level of a monorail is greater than that of an ordinary train, it is recommended that platform doors be installed.



Source: JICA Study Team and Tama Monorail

Figure 7.23 Platform screen doors of Tama Monorail station in Japan

2) Smooth transition between the train and platform

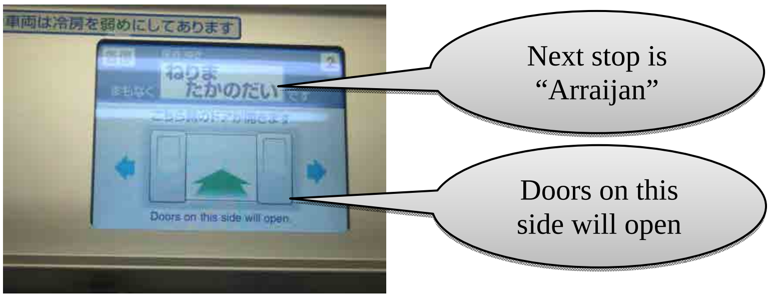
In the Japanese standard, the horizontal and vertical gap between the train and the platform shall be minimized. Smooth transition is recommended.

Source: JICA Study Team

Figure 7.24 Smooth transition between the train and platform

3) Voice information and notification display

Voice and monitor information on train operation are recommended for handicapped users.



Source: JICA Study Team and Toei Subway, Japan

Figure 7.25 Notification LCD Display in the train

4) User-friendly elevators and escalators

In Panamá, elevators and escalator in the public space are now being designed to be user friendly.

- The buttons of the elevators are set within the reach of the wheel chair passengers and they have Braille signs for the blind and voice information.
- Handrails in elevators for handicapped users
- Voice information for blind passengers
- Easily viewable edge of the escalators steps
- Three flat steps on escalators for handicapped users

Braille indications for blind people in elevators

Smooth ramps for wheel chairs

Source: JICA Study Team

Figure 7.26 User-friendly elevators and escalators

5) Station layout map of the facilities for handicapped users

A station layout map of the facilities for handicapped users is recommended. Figure 7.27 shows an example of the station layout map for the Osaka Monorail in Japan.

Source: Osaka Monorail, Japan

Figure 7.27 Station layout map of the facilities for handicapped users

7.6.4 Structure of the stations

For the elevated stations of urban transport systems, generally a three-story building is proposed, with a platform level, concourse level and ground level (road level).

A roof is installed and fences for safety are equipped on the platform. At the platform level, passengers wait for and board trains. Also, passengers alight from trains to the platform and move to the concourse level.

At the concourse level, passengers who will board trains buy tickets and pass through the ticket gates. If passengers need some information regarding train operation, the staff in the station office located on the concourse level will assist them.

Since all the monorail stations are elevated and most are located over a road, stairs and other means of access are provided from the ground level to the concourse. Since the station access connects both sides of the road via the concourse, it can also function as a pedestrian bridge for the general public to cross the road.

The station are open to the air without air condition except for staff rooms.

7.6.5 Platform type

(1) Type

Two types of platforms are examined for the typical stations. One is the Island type and the other is separated type platform. Table 7.18 shows a comparison of the two types of platforms to be adopted in designing the monorail system.

In this project, the separated type platform is employed because of the advantage in the horizontal alignment.

Table 7.18 Comparison of Station platform types

Item	Island type	Separated type
Image view		
Description	In the approach section of stations, the tracks spread out in a “fan shape” and the platform is located between the tracks.	The platforms are separated by the tracks. The distance between tracks in the approach section of station is kept the same as the normal section.
Alignment	Train running performance and comfort are inferior to the separated type platform because of a “fan shape” alignment.	The distance between tracks does not spread in the approach section of the station. (+)
Station Facility	Compared to the separated type platform, the number of facilities such as elevators and escalators can be reduced. (+)	Facilities such as stairs, elevators and escalators are required for each platform.
Width of the structure	Total width will narrower than the Separated Type. (+)	Total width will be slightly wider than the Island Type.
Guide-way Structures	Guide-way structure has to be widened and construction costs shall be more than the Separated Type.	Continuous and parallel guide-ways. (+)
Maintenance	Station staff can perform duties for both directions of travel owing to the single platform. (+)	Necessary to dispatch staffs to each platform.
Train Operation	The train has to reduce its speed in front of the curve and the average speed shall be less than the Separated Type.	There is no curve in front of station. (+)
Others	From the viewpoint of operation, the type of platform is frequently standardized for an entire line. (Separated type: Tokyo Monorail, Tama Monorail / Island Type: Osaka Monorail / Mixed Type: Okinawa Monorail)	

* (+) shows advantages
Source: JICA Study team

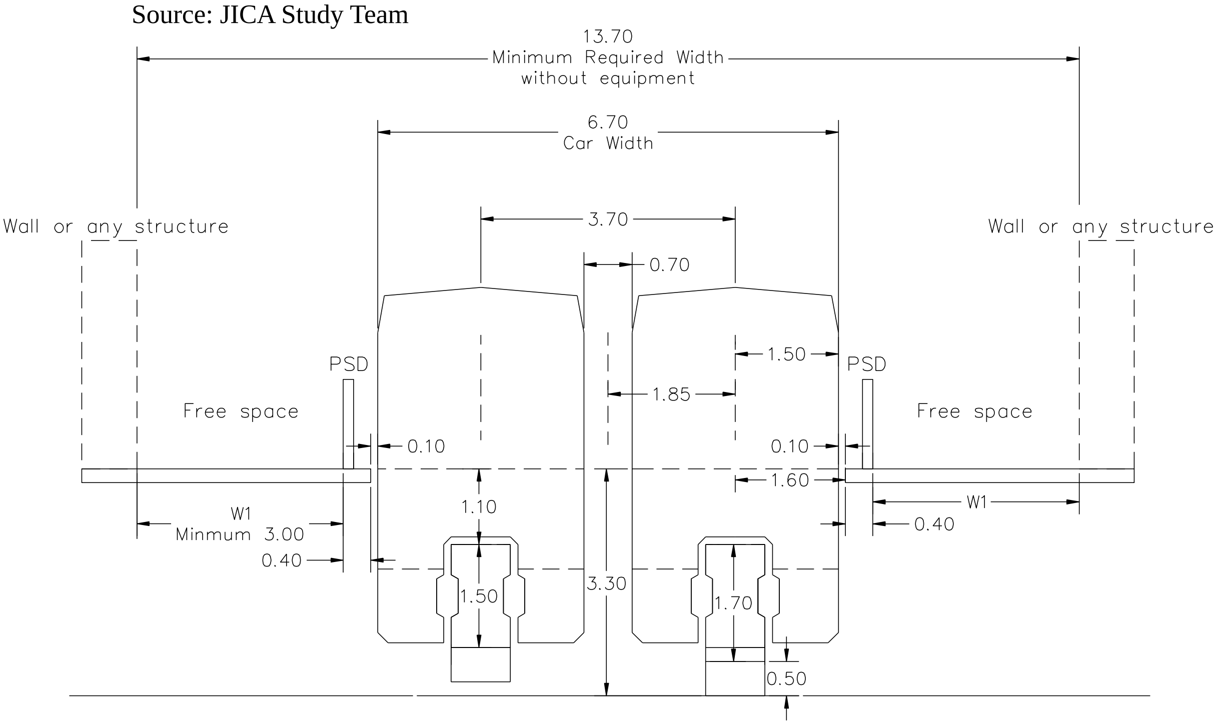
(2) Platform Width

The required widths of the platforms are calculated from the expected passenger volume during peak hour. As project policy, a 3m width will be secured for the platforms for the circulation of passengers. This is wider than normal practice in other countries where the minimum free width (no walls or any other type of structures) is between 1.2m and 1.5m. The following table shows the required free space width of the platforms at each station.

Table 7.19 Platform width

Name of station	Type (defined in 7.1.1)	Width of PF W1= (m)
1.Albrook Station	Major Interchange Station	4
2. Balboa Station	Exchange Station	3
3. Panama Pacific Station	Exchange Station	3
4. Loma Coba Station	Exchange Station	3
5. Arraijan Station	Exchange Station	3
6. Arraijan Mall Station	Major Interchange Station	3
7. Burunga Station	Exchange Station	3
8. Nuevo Chorrillo Station	Park and Ride Station	3
9. Caceres Station	Exchange Station	3
10. Vista Alegre Station	Major Interchange Station	3
11. Vista Alegre 2 Station	Exchange Station	3
12. Nuevo Arraijan Station	Exchange Station	3
13. San Bernandino Station	Exchange Station	3
14. Ciudad del Futuro Station	Major Interchange Station and Depot	3

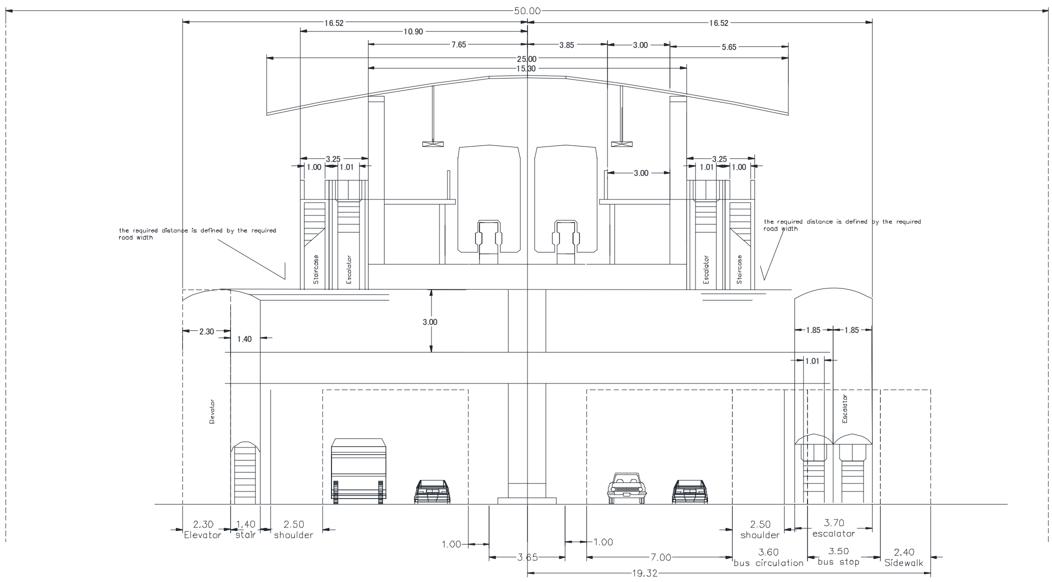
Source: JICA Study Team



Source: JICA Study Team

Figure 7.28 Cross section of Station (Platform)

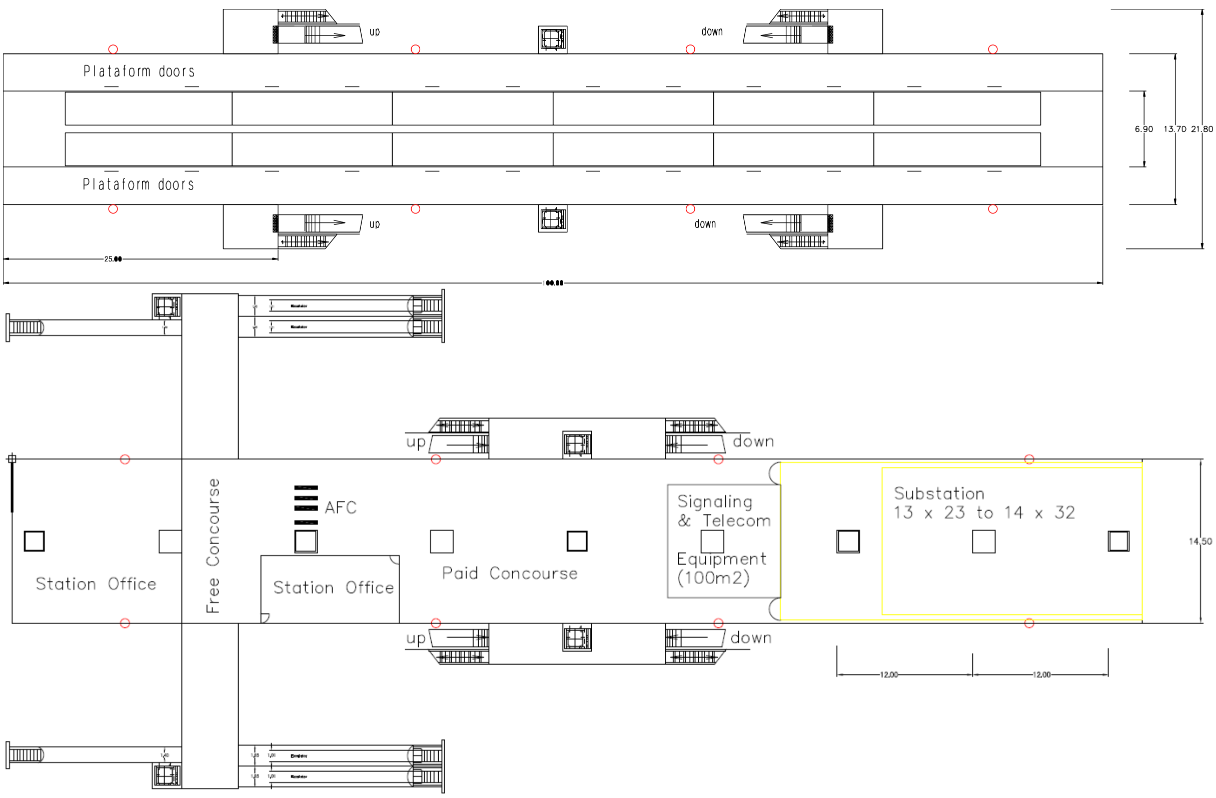
In the typical stations (all stations except Albrook and Nuevo Chorillo), w=38.64m is required in total. The total width includes width for bus stop and sidewalks. The required width for platform is w=15.3 m including column for roof, and 21.8 m in total including elevators, escalators and staircases which are attached out of platform. The stations can be constructed within the ROW of Pan American Road which has w=50 m of ROW. Figure 7.29 shows planned road cross section at station location.



Source: JICA Study Team

Figure 7.29 Road Cross Section at Station

Plan layout of stations is shown in Figure 7.30. Escalators and staircases are installed at 25 m from the edges of platform and the elevator in the middle. This layout complies with NFPA130 which is used as safety standard in Panama. Ticket window, ticket date, E&M room, signaling and telecommunication equipment room and substations are located in the concourse level. Figure 7.30 shows an example of layout with substation.



Source: JICA Study Team

Figure 7.30 Station Layout

7.6.6 Platform Screen Door (PSD)

(1) Purpose of PSD

Platform screen door (PSD) systems are introduced in many urban transport systems for the following purposes:

a) To ensure passenger safety

b) To reduce unauthorized access to the trackside

c) To prevent accidental falls of passengers

d) To save station monitoring staff load

e) To maintain comfortable air conditioning (Subway and high temperature area, etc.)

Although the purpose e) above is not related to Line-3, it is recommended that PSD is introduced to Line-3 for the purposes a) - d).

(2) Consideration of train operation system

There are three types of train operations in urban transport systems, namely one-driver operation, driverless operation, and an un-attended train operation (UTO). The need for PSD is also related to the selection of the type of train operation.

Line-3 will employ the one driver operation with ATO, which is defined as GoA2 (Grade of Automation level 2) by the International Association of Public Transport (UITP). In case of GoA2, PSD is not necessarily required.

However, even in the case of one driver operation with ATO, in many systems the PSD is introduced in order to ensure passenger safety.

(3) Type of PSD

There are two types of PSD: half-height type and full-height type. There are some differences in the purpose of these two types and the most appropriate type needs to be selected according to the environment of the metro line.

In addition to its main purpose of ensuring passenger safety, the full-height type PSD enables efficient air conditioning inside stations by segregating inner area of the stations from outside areas. Since the platforms of Line-3 are located in elevated stations without air conditioning, full-height PSD is not needed. Therefore, the half-height PSD is recommended for Line-3.

(4) Operational Requirement

The PSD system consists of a structure with sliding double doors, an opening and closing apparatus with its controller, fixed screens, emergency walkway doors, sensors, a control system, power supply and other necessary facilities. The PSD should be designed to accommodate a 6-car train. The doors of the PSD are located at positions corresponding to the train cars.

The PSD should be in automatic mode for normal operation. The command to open the doors is sent to the PSD control unit after the train is stopped by the ATO at the stop point.

The command to close the doors is normally sent by the train operator in the cab. The command is sent to the PSF control unit after the driver confirms the safety of closing the doors of the train cars and the PSD. Images of the platform are transmitted to the cab to be displayed so the driver can check for safety.

In case an obstacle is detected at the door-closing phase, the door shall be stopped and opened and the obstacle shall be removed. Automatic open and closure should be repeated at pre-set intervals until complete closure is detected.

When all the doors are closed and locked, an “All Doors Closed” indication is transmitted to the on-board ATO/ATP units.

PSD operation by the driver and station staff should be provided on the local control panel located near the train cab in case of failure of the automatic facilities.

In case of electric power failure, each door may be manually opened from the trackside or from the platform side.

(5) Configuration of Half-height PSD system

Figure 7.31 shows the Platform Screen Door system (PSD). The function of each device is as follows:

1) Platform Screen Door (PSD)

All platform screen doors are located at the platform edge corresponding to the location of the train doors. PSD control units are stored in the PSD footer or side box.

2) Manual Secondary Door (MSD)

Manual doors providing access from the platform onto the trackside are located at the end of all platforms. Each MSD shall be equipped with a manual release using a push bar, which can be controlled at the trackside and platform side.

3) Emergency Escape Door (EED)

EED’s shall be located at the position corresponding to the leading car, close to the MSD, and the tail car. Each EED shall have an emergency manual release mechanism, which is equipped with a push bar at trackside or operated by a staff key at the platform side.

4) Fixed Screens (FP)

All fixed screens associated with the PSD System are termed “Fixed Screen” (FP) and shall fill the gaps between the PSDs along the platform edge.

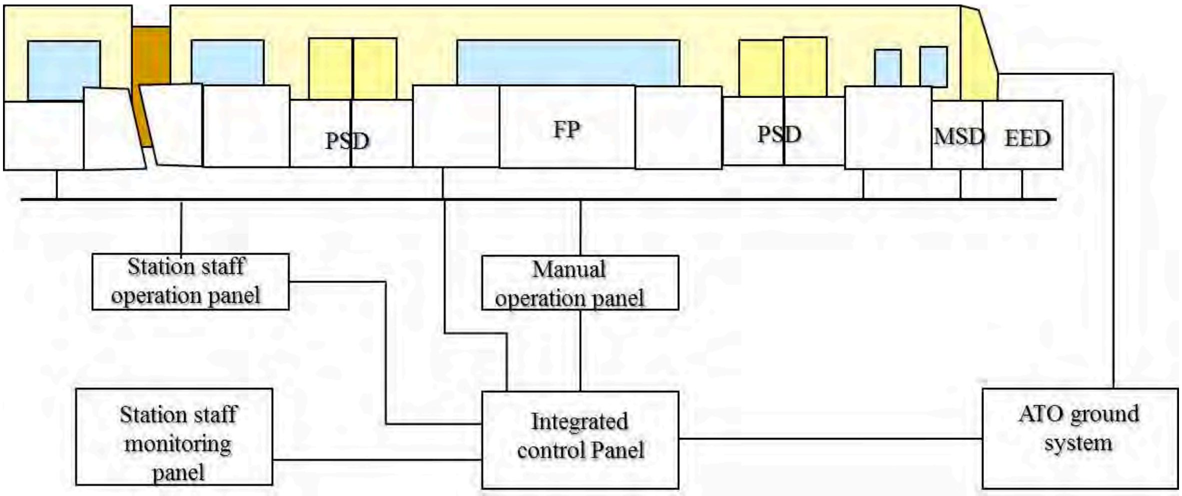
5) Control Unit

The control unit is located in the station staff room, and has the following functions.

- Opens the PSD doors based on the signal indicating the stoppage of the train at the fixed-point, which is received from the balise of ATO on the track.
- Monitors the operating conditions of PSD, MSD, and EED and the alarm signal.

6) Others

The PSD shall also include alarms, signs, power supply and other necessary facilities.



Note; PSD; Platform Screen Door, MSD; Manual secondary Door, EED; Emergency Escape Door, FP; Fix screen Panel

Source: JICA Study Team

Figure 7.31 Platform Screen Door System

7.6.7 Automatic Fare Collection

(1) General

Panama Metro Line 3 system will handle a large number of passengers. Ticketing and fare collection play a vital role in the efficient and proper operation of the system enabling the correct collection of fares and preventing fare evasion. To achieve this purpose, an Automatic Fare Collection (AFC) system should be introduced to Line-3. Metro Line-1 and Metrobus have already introduced AFC systems using Type-A contactless IC Card. AFC as following features.

1) Characteristics of Automatic Fare Collection (AFC)

a) Improved cost efficiency by adopting a Contactless IC card ticket.
b) Automatic gates makes it is possible to shorten passenger processing time.
c) Improved efficiency makes it is possible to reduce the number of station staff.
d) Automatic checking of every ticket at the gates makes it is possible to reduce the possibility of unauthorized rides.
e) Quick and easy change of fare.
f) Easy and faster issuing of management information reports
g) Inter-operability with other transport system operators by using a common card.
h) The Contactless IC card may be used for other applications.

In view of the above, the computer based Automatic Fare Collection system is an effective solution.

2) Contactless IC Card

The Contactless IC card is the core media of the Automatic Fare Collection system, having such features as:

a) High speed processing: This enables faster passenger handling.
b) Accurate capture of OD (Origin and Destination) data, which, by processing properly, can be used for marketing information.
c) Cost saving: The cost of contactless IC cards is lower than that of conventional magnetic tickets because contactless IC cards need no physical contact and can be reused easily. AFC can reduce personnel expenses related to ticketing.
d) Easy maintenance: Since its environment is less susceptible to dust and wear, it can save maintenance cost.

(2) Selection of a Contactless IC card

There are three types of the Contactless IC cards: Type-A, Type-B, and Type-C. The Type-A card was introduced in the Metro Bus and Metro Line 1. Contactless IC cards are standardized. In ISO/IEC21481, R/W including all radio interfaces are standardized for Type-A, Type-B, and Type-C. Frequency is 13.56MHz.

1) Comparison of Contactless IC Cards for Metro Line-3

Table 7.20 summarizes a comparison of Type-A, Type-B, and Type-C cards for the selection of the contactless IC card system to be used in Line-3.

Table 7.20 Comparison of Contactless IC cards

Card Type	Merit	Demerit	Rating
Type-A	Type-A is popular as a transportation card. Metro Bus and Metro Line-1 use Type-A. Use of Type-A in the Metro Line-3 can ensure full compatibility with other transit systems in Panama.	Processing speed is lower than that of Type-C. Security level is not high.	Recommended because there is no problem.
Type-B	Type-B is popular as a transportation card next to Type-A.	Processing speed is lower than that of Type-C. Security level is not high.	Not recommended because there is no positive incentive to replace existing Type-A with B.
Type-C	Processing speed is fast. Security level is high. In addition to ticket use, Type-C can be used as electronic money. Type-C can be extended to mobile phones. Future development is high. Type-A cards can be used in Type-C equipment.	Type-C cards cannot be used for Metro Bus and Metro Line-1.	Recommended due to its high value function, although replacement of existing devices is necessary.

Source: JICA Study Team

2) Consideration

If the Type-A card is used, the compatibility among the Metro Bus network, Metro Line-1 and Metro Line-3 will be possible. However, because of the advantages of the Type-C card, such as high speed processing, high security and future development (extension to mobile phone, etc.), Type-C would be a candidate proposal.

If an R/W device conforms to ISO/IEC21481, it can communicate with Type-A, Type-B, and Type-C cards because ISO/IEC21481 was standardized to ensure the compatibility of these types. Since no contactless IC card is compatible with all three card types, the R/W devices must conform to multi-communication in order to permit all three types of contactless IC cards to be used interchangeably. To enable Type-A card in Line-3 system, R/W devices that conform to ISO/IEC21481 need to be used. Such multi-communication type R/W devices would be required to enable the usage of Type-C card in Metro Bus and Line-1.

If Metro Line-3 adopts the Type-C contactless IC cards, the basic need for complete card compatibility (interoperability among Metro Bus, Metro Line-1, Line-2 and Line-3) will not be satisfied even if ISO/IEC21481 standard R/W devices are adopted. In order to completely satisfy this requirement, there is no choice but to select the Type-A card for Line-3.

(3) Ticketing and fare adjustment

A method similar to that used by Metro Bus is proposed for ticketing and fare adjustment.

1) Contactless IC cards are sold by vendors in a face-to-face vending system, while value (money) is added to the cards by automatic vending machines.
2) A card lacking fare is blocked at the gates. In this case, station staff adjusts the lack of fare by using a ticket office machine (TOM). Specialized automatic fare adjustment machines are not introduced.
3) Ticket Readers, which can check the balance of the cards, are installed near the gates in the stations.

(4) Requirement of AFC equipment

Retractable flap type control gates, which offer high throughput and require less maintenance, are proposed for the Metro Line-3. In fact, this type of gate is the latest technology in modern metros worldwide. Tripod turnstile gates offer low throughput and require more maintenance.

Flaps are usually receded from the aisle into the gate structure during “Peak Mode” as selected by the gate control unit, but flaps are projected forward into the aisle and an alarm lamp flashes if an unacceptable card is detected by the Reader/Writer. By contrast, when the “off-peak” mode is selected by the gate control machine, the flaps are normally projected out into the aisle and recede each time an acceptable card is detected, while the flaps stay projected and an alarm lamp flashes when an unacceptable card is detected.

An example of the Retractable flap type Control Gates is shown by Figure 7.32.

Source: JICA Study Team

Figure 7.32 Entry/Exit Gates

The requirements of AFC equipment is shown by Table 7.21

Table 7.21 Requirement of AFC equipment.

Standards	Description
Fare media	a) Contactless IC card: Type-A or Type-C card is adopted. If Type-C card is adopted, a standardized R/W device that conforms to ISO/IEC21481 needs to be used. b) Contactless token is not used.
Gates	Computer control of retractable flap type automatic gates at entry and exit. Gate types are: • Entry only • Exit only • Reversible (can be set to entry or exit) • Wide reversible gate for disabled people All have reader/writer devices. The reader/writer devices should meet ISO/IEC21481 standards if using Type C cards.
Gate Control Unit	A gate control unit is located in the station staff office in each station to ontrol the gate status between “Peak” and “Off-peak” periods. In the case of emergency, the gate control unit releases all gates from operation mode.
Add value Machine (AVM)	This is used for adding money to the contactless IC cards. Contactless IC cards are sold at ticket offices.
Station server, Central server and AFC Network	All fare collection equipment shall be connected to a local area network with a station server which controls the transactions of all the machines and operation status. These station servers are linked to the central computer situated in the operation control center through optical fiber communication channels. The centralized control of the system shall provide real time data of earnings and passenger flow analysis**.**
Ticket office machine (TOM)	Manned ticket office machines shall be installed in each station for selling cards to the passengers and validating the cards if needed. This machine has a reader/writer device.
Ticket Reader and Portable Ticket Validator.	Ticket readers shall be installed at the concourse entrance and near gates for passengers to check information stored in the cards. A portable ticket validator is a handheld type TOM with validation functions for only staff use.
UPS (uninterrupted power at stations as well as for OCC).	UPS is used to maintain the electric power supply to AFC equipment for one hour in case of a shutdown of normal power lines.
Maintenance	Being fully contactless systems, the manpower requirement for maintenance is much less compared to that of a system with magnetic tickets.

Source: JICA Study Team

(5) Installation of AFC equipment

The necessary number of AFC equipment at each station is calculated as shown in Table 7.22. The total number of each equipment is:

1) Number of gates

The necessary number of gates is calculated based on the assumption that the average number of persons passing through a gate is 45 persons per minute.

a) Standard type; 29
b) Reversible type; 8, c) Total = 37

2) Installation of AVM

a) Terminal stations; 4sets/station-------8sets
b) Intermediate stations; 2 sets/station------24sets, c) Total = 32

3) Installation of TOM

a) Terminal stations; 4sets/station-------8sets
b) Intermediate stations; 2sets/station-------24sets, c) Total = 32

4) Ticket reader

a) Terminal stations; 4sets/station-------8sets
b) Intermediate stations; 2sets/station-------24sets, c) Total = 32

5) Ticket portable validator-----15sets Total =15

6) UPS

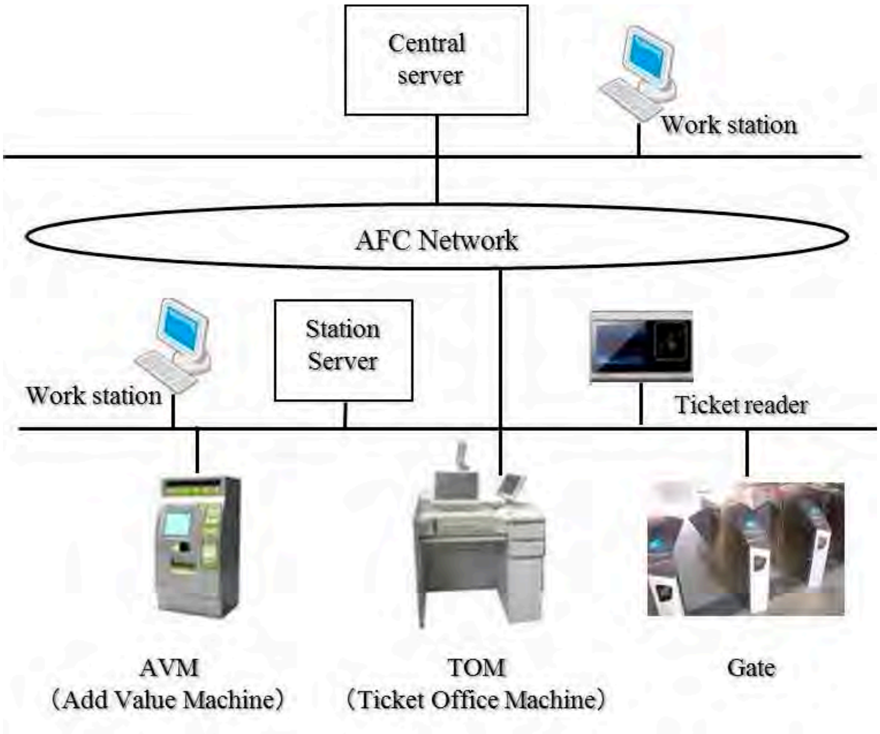
a) CCR (Central Control Room)-----1 set
b) SCR (Station Control Room)-----14 sets, c) Total = 15

Table 7.22 Installation of AFC gates

Station	Board			Alight			Total No. of Gates
	To West	To East	No. of Gates	From West	From East	No. of Gates	
Albrook	2,472		1	20,582		8	10 (R)
Balboa	113	205	1	290	179	1	2
Panama Pacifico	534	392	1	309	0	1	2
Loma Coba	1	1,079	1	16	48	1	2
Arraijan	193	2,577	2	159	196	1	4
Arraijan Mall	6	1,266	1	10	77	1	2
Burunga	4	3,186	2	41	182	1	4
Nuevo Chorrilo	0	1,753	1	10	523	1	2
Caceres	0	711	1	0	180	1	2
Vista Aregre	0	3,517	2	0	345	1	4
Vista Aregre 2	0	1,367	1	0	224	1	2
Nuevo Arraijan	0	1,260	1	0	273	1	2
San Bernardino	0	2,092	1	0	402	1	2
Ciudad del Futuro		2,012	1		694	1	2

Source: JICA Study Team

System configuration of AFC is shown by Figure 7.33.



Source: JICA Study Team

Figure 7.33 System configuration of AFC (Automatic Fare Collection system)

7.6.8 Utilization of Japanese Technology and Experiences

(1) Property Development within Station Premises

Layout of Panama Metro Line 1 stations are designed considering smooth flow of passengers, and providing less space for business purpose due to the short length of the line. There is no toilet in the intermediate stations except Albrook terminal. Kiosks are not planned.

On the other hand, it is easy to find toilets and kiosks in railway station in Japan due to longer distance or longer travelling time. Recently, property development utilizing station premises is booming in Japan. Statistic data indicates that the average income from non-fare business is exceeding 10% of the total income of major private railway companies in Japan. The maximum ration was 17.9% in 2013. The Tokyo metro was 10.9%.

Since the line length of Panama Metro Line 3 will be more than 30km in future, toilet facilities will be required at major stations. Space for kiosks will be provided within station area. Park & Ride spaces will also be provided in front of potential stations.

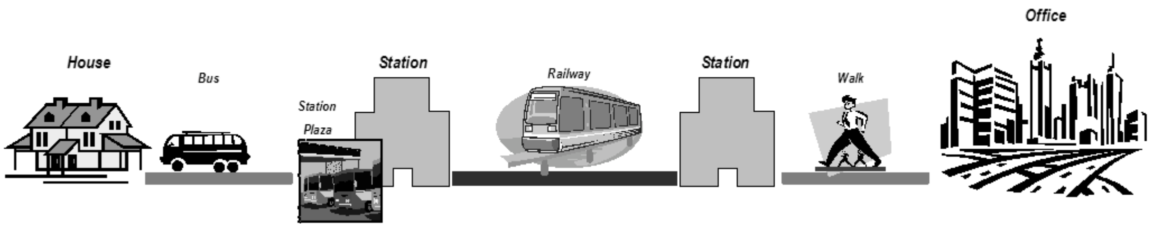
(2) Crime Prevention System within Station Premises

It is necessary to provide a crime prevention system within station premises and inside of trains. Monitoring by CCTV system is effective for the purpose, especially at night, when and where dark and number of passengers is less. It is recommended to use high resolution and high sensitive CCTV not to make blind spots within the monitoring area. Crime inside of train shall also be prevented by installing CCTV cameras inside of each car. In order to prevent crimes, it is recommended to organize Railway Police who has powers to arrest criminals within the railway premises.

7.7 Intermodal Facilities

7.7.1 Objectives of Intermodal Facilities

Generally speaking, transportation from an origin to a destination will often consists of using a number of transportation modes and making connections between them. For example, Figure 7.34 shows two connections being made between three different transport modes: transferring from a bus to a railway and from the railway to walking.



Source: JICA Study Team

Figure 7.34 Traffic Movement

In order to achieve the permanent use of a monorail system, it is important to provide not only good monorail service, but also adequate intermodal transfer facilities for connecting with the other transport modes. In other words, if a smooth transfer between monorail and other transport modes is provided, which means reducing the resistance to making intermodal connections, the number of persons using the monorail would increase.

In general, the resistance to making connections to other transport modes occurs due to the following situations:

- High frequency of climbing and descending, and
- The walking distance from one station to another transport mode station is more than 200m.

In order to avoid this type of resistance, it is important that the intermodal facility is developed in conjunction with the railway construction.

(1) Case Examples of Intermodal Facilities

The case examples of Intermodal facilities are shown as below.

Table 7.23 Case Examples of Intermodal Facilities

Large-Sized Intermodal Facility (Station Plaza)	Park and Ride Facility	Bus stop
 Sakuragi-Station, Yokohama City, Japan	 Towada City-Station, Aomori Prefecture, Japan	 Funabashi-Station, Chiba Prefecture, Japan
The station plaza has the role of not only of providing transfers, but also plaza amenities and services. The service level should be based on user characteristics, but there should also be sufficient space to meet future demand.	Park and Ride is one type of transfer between railway service and feeder traffic. In general, a large parking lot is constructed for car users. The facility has a beneficial effect on the feeder traffic of private car users in their access to the railway station. In addition, the facility eases traffic jams in the city center when passengers transfer from car to monorail at the station using the adjacent parking lot at a discount price.	In general, resistance to horizontal connection to other transport modes would occur when the walking distance is more than 200m. The bus stop or taxi bay for the intermodal facility should be installed within this distance. In case there is already a bus stop where station will be constructed, the entrance to the station should be set at a short distance from the existing bus stop.

Source: JICA Study Team and Station Plaza Guideline of Toyota Transportation Research Institute

(2) Screening of Station Type

1) Screening of Station Type

Based on the case examples mentioned above, the following 3 types of stations are provided according to demand and the characteristics of the region.

- Major Interchange Station
- Exchange Station
- Park & Ride Station

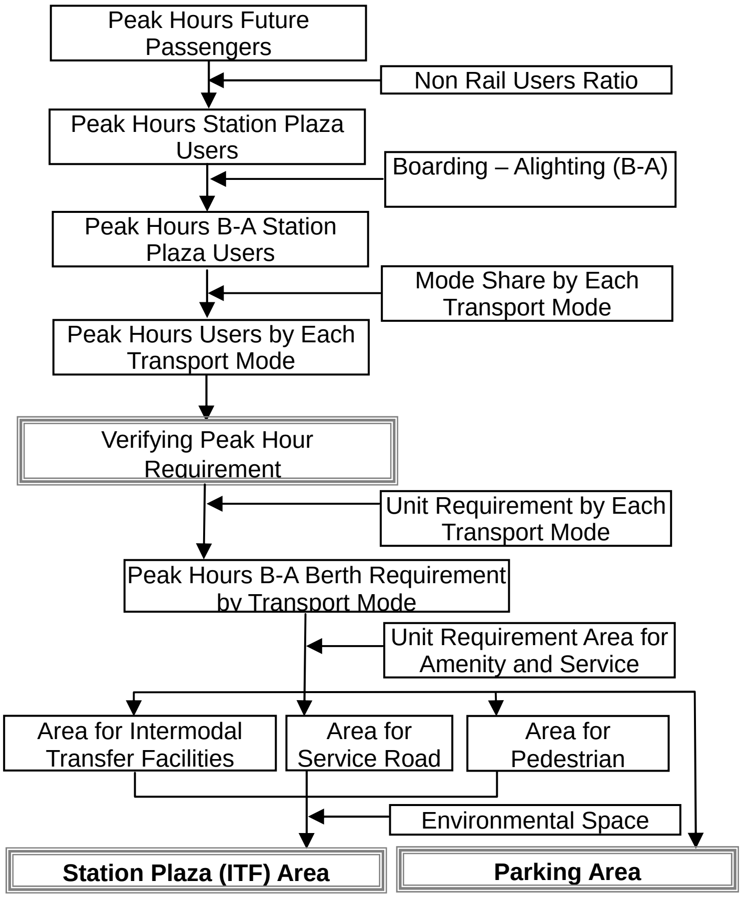
The Major Interchange Station has the function of a large scale facility for making transfers between various public transportation modes. In addition, it should be a connection point between the station and the origin or destination of a passenger's trip.

The Exchange Station has the role of providing transfers from feeder traffic to mass rapid transit, in this case the monorail. Easy access between both transportation modes is crucial. In case there are already bus stops where the station is to be located, they will be used as a base for continuous feeder traffic once the railway operation begins.

The Park and Ride Station has a large-sized parking lot for commuting passengers who arrive at the station in their own cars. This type of station is installed in a suburban area when there is a lack of public transportation service in the area.

2) Calculation Method of Intermodal Facility

The process for determining the required number of Intermodal Facilities is shown in Figure 7.35. This process is based on the Station Plaza Planning Guideline of the Ministry of Land, Infrastructure, Transport and Tourism of Japan of 1998. It is a flow-chart for making a general estimation.



Source: JICA Study Team

Figure 7.35 Process for Determining the Required Capacity of a Station Plaza

The facility scale is calculated based on the demand forecast. In the process of demand forecasting, the total passengers that will transfer from other transport modes to the monorail after its opening, is established. This number is further classified by access mode from the place of departure to the station, whether by walking or feeder traffic. The number of walking passengers follows as mentioned above. In addition, each type of feeder traffic, for example, bus, taxi, private car and so on, is estimated according to the results of the traffic surveys that were conducted in this study. This means that the estimated number of each feeder traffic incorporates the local characteristics regarding traveling customs.

In this section, the scale of the facilities for the Ciudad del Futuro Station, which is the largest in this project, is presented as a case example.

The transport modal share of Ciudad de Futuro Station is shown in Table 7.24. The coefficients for calculating Station Plaza Capacity by traffic mode are set as seen in Table 7.25.

Table 7.24 Assumed modal share

Mode	Code	Modal Share
Bus	Mb	41%
Minibus	Mmb	1%
Taxi	Mt	34%
Pirata	Mst	1%
Car (Kiss & Ride)	Mck	11%
Walk	Mw	9%
Bike	Mbk	0%
Car (Park & Ride)	Mcp	5%

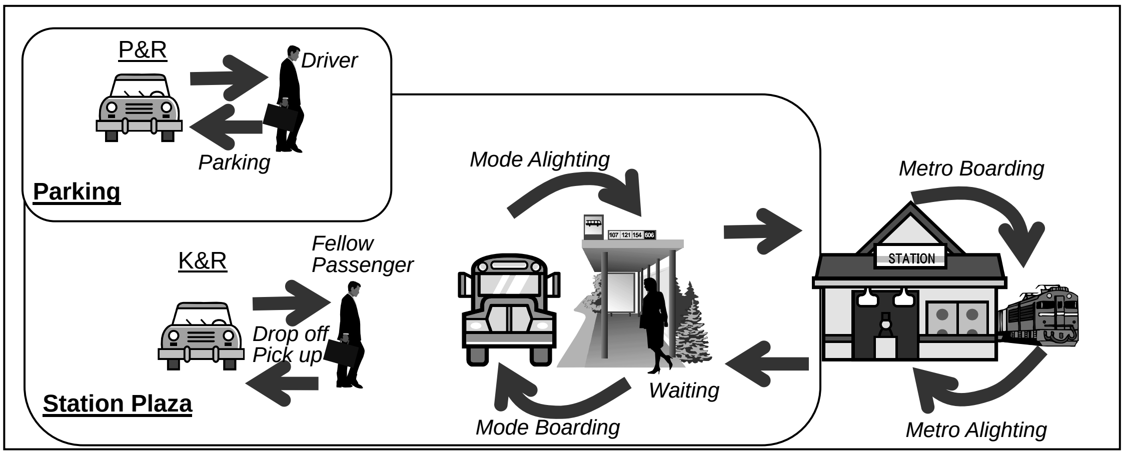
Source: JICA Study Team based on Demand Forecast and Traffic Survey

Table 7.25 Coefficients for calculating Station Plaza Capacity by traffic mode

Items	Code	Bus	MiniBus	Taxi	Pirata	Car	Bike	Unit
		b	*mb*	*t*	*st*	*c*	*bk*	
Average passenger service	P*x*	40	30	2	5	1.3	1	person/car
Time required to board	T*bx*	-	-	10	10	60	30	/60 min/berth-person
Time required to alight	T*ax*	2	2	30	30	1	1	/60 min/berth-person
Headway to wait	H*x*	2	2	5	5	-	-	min/car

Source: JICA Study Team based on the Station Plaza Planning Guideline of the Ministry of Land, Infrastructure, Transport and Tourism of Japan of 1998

An image of transfers made by passengers at the station and station plaza is shown in Figure 7.36. Boarding and alighting for each mode and for the monorail are also shown.



Source: JICA Study Team

Figure 7.36 Image of Station Transfers and Station Plaza Users

Based on the above process, the required capacity of the intermodal facility in peak hours was calculated as shown in the following Table 7.26.

Table 7.26 Required Capacity at Peak Hours

Items		Equation	Quantity			Unit	Remarks
			2020	2030	2050		
Future passengers		P =	25,858	26,308	26,992	parson/hour	Demand Forecast
Future Station Plaza Users		N = P × 1.3	33,620	34,200	35,090	parson/hour	
Future peak hour passengers (boarding)		PPb =	571	682	848	passenger/day	Demand Forecast
Future peak hour passengers (alighting)		PPa =	2,532	2,475	2,391	passenger/day	Demand Forecast
Peak hour station plaza users		PTU = PPb + PPa	3,103	3,157	3,239	parson/hour	
Peak hour station plaza users (boarding)		PTUb =PPb × 1.3	740	890	1,100	parson/hour	
Peak hour transport mode users (Mode boarding)	Bus	PTU*Mbx* = PTU*Mb* × (*Each Mode Share Ratio*)	300	360	450	parson/hour	
	Minibus		0	0	10	parson/hour	
	Taxi		250	300	370	parson/hour	
	Pirata		10	10	10	parson/hour	
	Car (K&R)		80	90	120	parson/hour	
	Bike		0	0	0	parson/hour	
	Car (P&R)		30	40	50	parson/hour	
Waiting passenger	Bus	PTW*b* = PTU*Mbx* × H*b* / 60	10	10	20	parson	
	Minibus	PTW*mb* = PTU*Mbx* × Hm*b* / 60	0	0	0	parson	
	Taxi	PTW*t* = PTU*Mbx* × H*t* / 60	20	30	30	parson	
	Pirata	PTW*st* = PTU*Mbx* × Hst / 60	0	0	0	parson	
Peak hour required berth (Mode boarding)	Bus	PBB*Mb* = {(PTU*bb* / Pb) × H*b*)} / 60	2	2	2	berth	Include 1 berth for Evening Peak
	Minibus	PMBB*Mb* = {(PTU*bmb* / P*mb*) × H*mb*} / 60	1	1	2	berth	Include 1 berth for Evening Peak
	Taxi	PTB*Mb* = (PTU*bt* × T*bt*) / 60	1	1	2	berth	
	Taxi Standby	PTL*Mb* = {(PTU*bt* × P*t*) / 60} / H*bt*	11	13	16	berth	
	Pirata	PSTB*Mb*= (PTU*bst* × T*bst*) / 60	1	1	1	berth	
	Pirata Standby	PSTL*Mb*= {(PTU*bst* × P*st*) / 60} / H*st*	1	1	1	berth	
	Short-time Parking	PCB*Mb* = (PTU*bc* / P*c* × T*c*) / 60	4	4	4	berth	Include 2 berth for emergency vehicles
	Parking-Car	·PPC = (PUb × Mpc / Tc) / 2	600	610	620	berth	2 cycles
	Parking-Bike	·PPBK = (PUb × Mpbk / Tbk) / 2	0	0	0	berth	2 cycles
Peak hour station plaza users (Metro alighting)		·PTU*Ma* =PP*b* × 1.3	3,290	3,220	3,110	parson/hour	
Peak hour transport mode users (Mode alighting)	Bus	·PTU*Max* = PTU*Ma* × (*Each Mode Share Ratio*)	1340	1310	1270	parson/hour	
	Minibus		20	20	20	parson/hour	
	Taxi		1110	1090	1050	parson/hour	
	Pirata		30	30	30	parson/hour	
	Car (K&R)		350	340	330	parson/hour	
Peak hour required berth (Mode alighting)	Bus	·PBB*Ma* = (PTU*ab* / T*b*) / 60	1	1	1	berth	
	Minibus	·PMBB*Ma* = (PTU*amb* / T*mb*) / 60	1	1	1	berth	
	Taxi	·PTB*Ma* = (PTU*at* × T*at*) / 60	10	10	9	berth	
	Pirata	·PTB*Ma* = (PTU*ast* × T*ast*) / 60	1	1	1	berth	
Traffic volume		·PV = Σ{PTU*bx* × (Each Mode Share Ratio)}	220	270	340	pcu/hour	Bus:1.7, Bike:0.5

Source: JICA Study Team based on the Station Plaza Planning Guideline of the Ministry of Land, Infrastructure, Transport and Tourism of Japan of 1998

The required berth area for each transport mode is summarized below.

Table 7.27 Required Berth Area for Each Transport Mode

Items	Unit berth area (m^2)	2020						2030						2050					
		Berth			Required area(m^2)			Berth			Required area(m^2)			Berth			Required area (m^2)		
		Boarding	Alighting	Total	Boarding	Alighting	Total	Boarding	Alighting	Total	Boarding	Alighting	Total	Boarding	Alighting	Total	Boarding	Alighting	Total
Bus Berth	70	2	1	3	140	70	210	2	1	3	140	70	210	2	1	3	140	70	210
Mini Bus Berth	35	1	1	2	35	35	70	1	1	2	35	35	70	2	1	3	70	35	105
Taxi Berth	20	1	10	11	20	240	260	1	10	11	20	200	220	2	9	11	40	180	220
Taxi Standby Lot	30	11	0	11	390	0	390	13	0	13	390	0	390	16	0	16	480	0	480
Pirata Berth	25	1	1	2	25	25	50	1	1	2	25	25	50	1	1	2	25	25	50
Pirata Standby Lot	35	1	0	1	35	0	35	1	0	1	35	0	35	1	0	1	35	0	35
Short-time Parking Lot	25	4	0	4	100	0	100	4	0	4	100	0	100	4	0	4	100	0	100
Total		-	-	-			1,015	-	-	-			1,075		-	-			1,200

Source: JICA Study Team based on the Station Plaza Planning Guideline of the Ministry of Land, Infrastructure, Transport and Tourism of Japan of 1998

The required waiting space for boarding each transport mode is shown as below.

Table 7.28 Required Waiting Area for Each Transport Mode

Items	Unit Wating Space (m^2)	2020		2030		2050	
		Waiting Parson	Required area(m^2)	Waiting Parson	Required area(m^2)	Waiting arson	Required area(m^2)
Bus	1	10	10	10	10	20	20
Mini Bus	1	0	0	0	0	0	0
Taxi	1	20	20	30	30	30	30
Pirata	1	0	0	0	0	0	0
Total		-	30	-	40	-	50

Source: JICA Study Team based on the Station Plaza Planning Guideline of the Ministry of Land, Infrastructure, Transport and Tourism of Japan of 1998

The space for vehicular roads and buffer space, which is road space, is shown below.

Table 7.29 Required Road Space for Vehicles

Items		pcu/hour	Road Length(m)	Width of Road (m)	Width of Margin(m)	Required area (m^2)
Road and Buffer for Vehicle	2020	220	120	3	2.5	660
	2030	270	140	3	2.5	770
	2050	340	170	3	2.5	935

Note: Road Length Lc = 0.4×PV + 36.1
Source: JICA Study Team based on the Station Plaza Planning Guideline of the Ministry of Land, Infrastructure, Transport and Tourism of Japan of 1998

The space required for pedestrians in the Intermodal Facility is shown below.

Table 7.30 Required Pedestrian Space

Items		Pedestrian	Density	Length	Required area (m^2)	Remarks
Pedestrian Space	2020	3,103	27	100	190	A= 1,705
	2030	3,157	27	100	190	A= 1,885
	2050	3,239	27	100	200	A= 2,185

Note: Lw = (0.009 × A) + 82.4
Source: JICA Study Team based on the Station Plaza Planning Guideline of the Ministry of Land, Infrastructure, Transport and Tourism of Japan of 1998

The parking space needed for Park & Ride is shown below.

Table 7.31 Required Parking Space

Items	Unit Berth area (m^2)	2020		2030		2050	
		Berth	Required area (m^2)	Berth	Required area (m^2)	Berth	Required area (m^2)
Parking Lot	30	600	18,000	610	18,300	620	18,600
Parking-Bike Lot	1.14	0	0	0	0	0	0
Total		-	-	18,000	-	18,300	-

Source: JICA Study Team based on Demand Forecast and Traffic Survey

The above mentioned results are summarized below.

Table 7.32 Required Intermodal Facility in Ciudad de Futuro Station

Items	Required area (m^2)			Remarks
	2020	2030	2050	
Berth Area	1,015	1,075	1,200	
Waiting Area	30	40	50	
Road Space	660	770	935	
Pedestrian Space	190	190	200	
Amenity & Open Space	950	1,040	1,190	50% of above
Sub-total	2,845	3,115	3,575	
Parking Area	18,000	18,300	18,600	
Total	20,845	21,415	22,175	

Source: JICA Study Team

In addition, the JICA Study Team proposes installing a Stabling Yard for buses during night time operation. The required yard space is shown below. It is set for 50 vehicles.

Table 7.33 Required Intermodal Facility in Ciudad de Futuro Station

Items	Required area (m^2)			
	2020	2030	2050	
Stabling Yard Space	3,500	3,500	3,500	Bus Parking, 70m2

Source: JICA Study Team

From the above, the total area of the Intermodal Facility is calculated to be approximately 30,000 m2. Based on these characteristic, the facility layout shall be designed.

For other stations, the facility scale is calculated based on the same method mentioned above.

3) Proposed Plan for Intermodal Facility

The station type is set for each station. In addition, the services that are integrated in the station and the facility scale are summarized below.

Table 7.34 Proposed Plan for Intermodal Facility for each Station

Station Name	Connect to	Integration Service	Facility Scale for Intermodal
1. Albrook (0+000km) (Major Interchange Station)	➢ Integrate with MRT Line-1 and AGNT ➢ Access to Albrook Shopping Mall	● Connecting to MRT Line-1, AGNT and Shopping Mall	● Access deck to other facility
2. Balboa (2+050km) (Exchange Station)	➢ Internal Bus Traffic in Balboa area	● Normal Bus Bay	● Bus Bay (2)
3. Panama Pacific (6+650km) (Major Interchange Station)	➢ Internal Bus Traffic in Panama Pacifico and Veracurz area ➢ Taxi Service	● Bus Terminal ● Taxi Stop	● Bus Bay (3) ● Minibus Bay (2) ● Taxi Stop (8) ● Taxi Standby (58) ● Pirata Stop (3) ● Short-time Parking (8)
4. Loma Coba (12+400km) (Exchange Station)	➢ Internal Bus Traffic in Arraijan Area	● Normal Bus Bay	● Bus Bay (3)
5. Arrajian (14+350km) (Exchange Station)	➢ Access to Commercial Area(Super X-tra) ➢ Internal Bus Traffic in Burunga and Arraijan Area ➢ Taxi Service	● Normal Bus Bay ● Taxi Stop *(Sharing with Arrajian Mall)* ● Connecting Deck to commercial area	● Bus Bay (5) ● Taxi Stop (13) ● Taxi Standby (11)
6. Arrajian Mall (15+500km) (Major Interchange Station) (Park & Ride Station)	➢ Access to newly constructed shopping mall ➢ Bus Terminal ➢ Taxi Service ➢ Park & Ride	● Huge Sized Intermodal Facility ● Connecting Deck or pedestrian to commercial zone	● Bus Bay (2) ● Taxi Stop (1) ● Taxi Standby (4) ● Short-time Parking (3) ● Multilevel Parking (870)* (* Shared Use with Commercial use)
7. Burunga (16+400km) (Exchange Station)	➢ Internal Bus Traffic in Burunga Area	● Normal Bus Bay	● Bus Bay (3)
8. Nuevo Chorrillo (17+850km) (Park & Ride Station)	➢ Internal Bus Traffic in Neuvo Chorrillo ➢ Taxi Service ➢ Park & Ride	● Normal Bus Bay (Internal Bus Traffic in Nuevo Chorrillo Area) ● Park & Ride Space included Taxi Stop	● Bus Bay (2) ● Taxi Stop (7) ● Taxi Standby (12) ● Short-time Parking (3) ● Multilevel Parking (430)
9. Cáceres (19+600km) (Exchange Station)	➢ Internal Bus Traffic	● Normal Bus Bay	● Bus Bay (2)
10. Vista Alegre (21+450km) (Major Interchange Station) (Park & Ride Station)	➢ Arterious Bus Traffic from Vacamonte ➢ Taxi Service ➢ Park & Ride	● Huge Sized Intermodal Facility	● Bus Bay (2) ● Minibus Bay (1) ● Taxi Stop (13) ● Taxi Standby (8) ● Pirata Stop (3) ● Short-time Parking (3) ● Multilevel Parking (670)
11. Vista Alegre 2 (22+350km) (Exchange Station)	➢ Access to Commercial Area (Super Rey) ➢ Access to West Land Mall ➢ Internal Bus Traffic in Nuevo Arraijan Area ➢ Taxi Service	● Normal Bus Bay ● Taxi Stop ● Connecting Deck to commercial zone	● Bus Bay (2) ● Taxi Stop/Standby (5)
12. Nuevo Arrajian (23+550km) (Exchange Station)	➢ Internal Bus Traffic in Nuevo Arraijan Area ➢ Taxi Service	● Normal Bus Bay ● Taxi Stop	● Bus Bay (4) ● Taxi Stop/Standby (7)
13. San Bernardino (24+300km) (Exchange Station)	➢ Internal Bus Traffic in Nuevo Arraijan Area ➢ Taxi Service	● Normal Bus Bay ● Taxi Stop	● Bus Bay (4) ● Taxi Stop/Standby (12)
14. Ciudad del Futuro (26+100km) (Major Interchange Station) (Park & Ride Station)	➢ Internal Bus Traffic in La Chorrea ➢ Park & Ride ➢ Taxi Service	● Huge Sized Intermodal Facility	● Bus Bay (3) ● Minibus Bay (3) ● Taxi Stop (11) ● Taxi Standby (16) ● Pirata Stop (3) ● Short-time Parking (4) ● Parking (620)

Source: JICA Study Team

7.7.2 Universal Design in the Intermodal Facility area

It is necessary to install not only an accessible public transportation service, but also a universal design that everyone can use. Universal design needs to be applied to not only the station's structural design, but also to the area surrounding the station. If the environment around the station gives free access to disabled people, smooth transfer from the monorail to other transportation modes can be provided in a real sense.

The application of universal design in the station was already mentioned above and the facilities to which universal design need to be applied for ensuring smooth movement in and around the station are shown below.

Table 7.35 Proposed Application of Universal Design in the Intermodal Facility

	Item	Station Yard	Station Plaza	Railway Passage or Around Station
Barrier Free	Escalator	◎	—	—
	Elevator	◎	—	—
	Staircase rail	◎	○	—
	Braille block	◎	◎	◎
	Audio Assist	◎	◎	◎
	Remove of difference in level around pathway	—	◎	◎
	Disabled stall	◎	○	—
Providing Information	Visual Display Facility for Train Time Table	○	—	—
	Visual Display Facility for Integrated with other transport	◎	◎	—
	Polyglot Visual Display Facility	○	○	△
Reservoir Space	Bench	◎	○	—
	Waiting Room	○	○	—
	Roof on Bus Stop	—	○	—
Intermodal Transfer	Station Plaza	—	○	—
	Parking (for the disabled)	—	○	△
	Cycle parking space	—	—	○

◎:Indispensable ○:Necessary △:Possible
Source: JICA Study Team

7.7.3 Development Approach for Intermodal Facility

(1) Representative example of a Major Interchange Station

A Major Interchange Station includes a traffic plaza and parking space for Park & Ride. The scale of each station's facility was already shown in the previous section 7.7.1(2)2). The facility needs to be developed according to the facility scale. In addition, it is important that the following requirements are also met.

- (Case-1) Eliminate overlapping in traffic flow as much as possible
- (Case-2) Design with vehicle maneuverability in mind
- (Case-3) Create public amenity space, for example a garden

In case-1, vehicular movement should be restricted to one-way routes within the traffic plaza. The entrance and exit from the access road to the traffic plaza should also be one-way. This design increases safety in the traffic plaza by avoiding complicated traffic flow, and it also increases drivers' ease of mind by reducing the need to check for on-coming traffic.

In case-2, the traffic plaza cannot fulfill its function if the vehicles cannot circulate freely inside the plaza. If a vehicle drives over a curb because of restricted space, it endangers pedestrian safety. It goes without saying that the car may also be damaged.

Thus, an adequate drawing for the station plaza with sufficient vehicle locus needs to be considered at the design stage.

Table 7.36 Specification of Target Vehicle

Vehicle Type	Overall Length	Overall Width	Front Overhang	Wheelbase	Rear Overhang	Minimum Turning Radius
Passenger Car	4.7m	1.7m	0.8m	2.7m	1.2m	6.0m
Bus	12.0m	2.5m	1.5m	6.5m	4m	12m

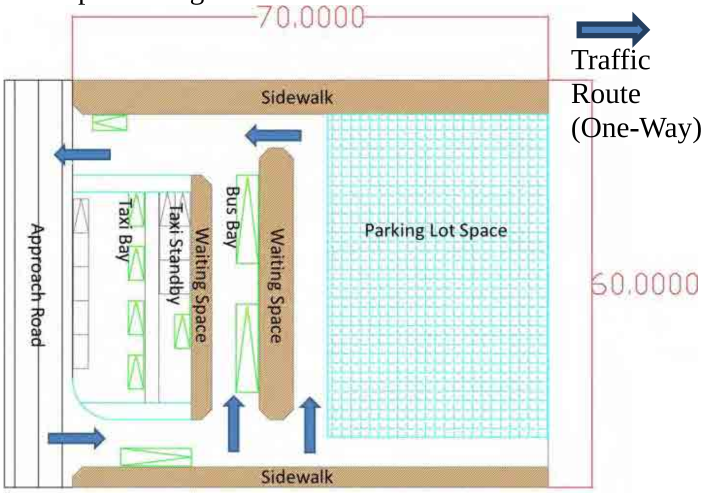
Source: Road Structure Ordinance in Japan

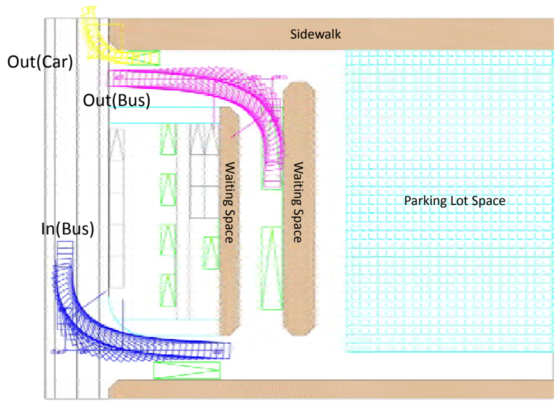
It is assumed that the maximum sized vehicle in the traffic plaza is a bus. The other vehicles will be normal passenger cars, which are used for designing the parking area. The critical point in the design is the splays inside the facility and the connecting points between the facility and the roadway/pedestrian way along the frontal road.

In case-3, the large-sized intermodal facility has the function not only of a traffic plaza, but also of providing amenity space. The amenity space can include various functions, e.g. the installation of a local disaster preparedness center. In general, the size of the amenity space is considered to be half the size of the traffic plaza.

Conceptual images of a Major Interchange Station that meet the above-mentioned conditions are shown below.

Conceptual Image





Facility Layout / Travelling Route Vehicle maneuver

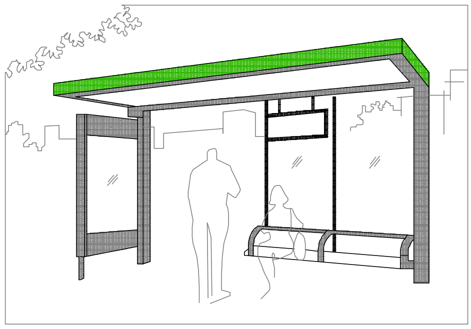
Source: JICA Study Team

Figure 7.37 Representative example of Major Interchange Station

(2) Representative example of Exchange Station

The Exchange Station has the role of providing transfers from the monorail to the feeder traffic. The stations are located in areas that are already used as an exchange point for local traffic with a bus stop. These bus stops are in constant use as the hub for local transportation. The entrance to the station needs to be a short distance from these existing bus stops.

Birds-Eye View



Design for Bus Stop

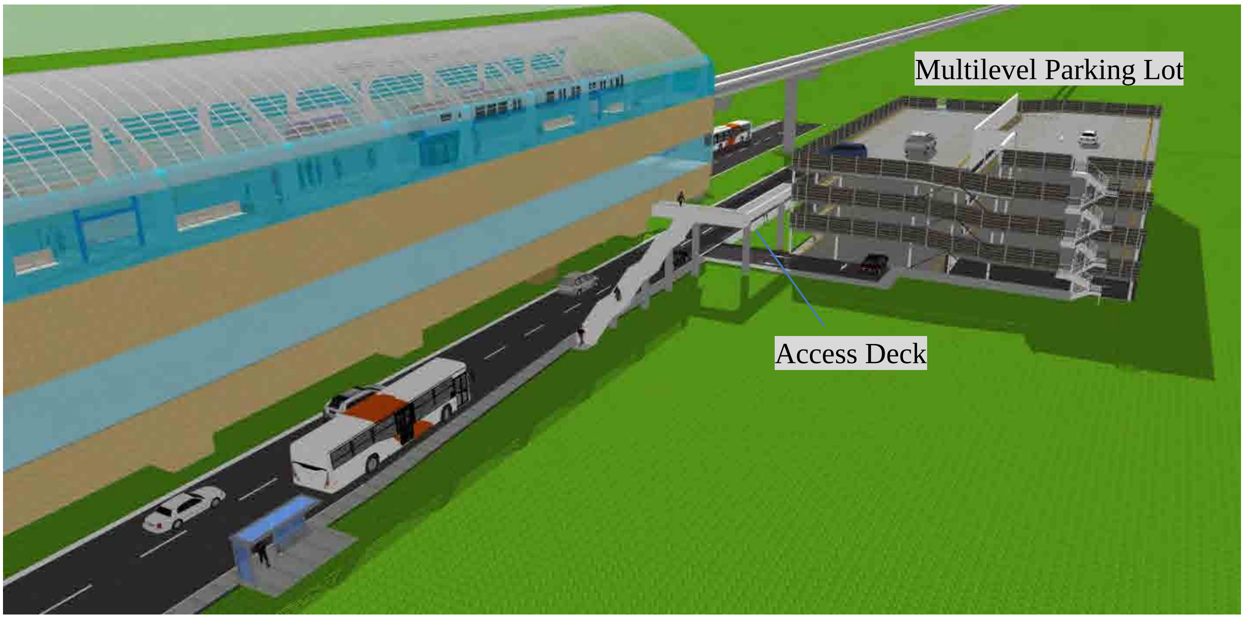
Source: JICA Study Team

Figure 7.38 Representative example of Exchange Station

(3) Representative example of Park and Ride Station

The Park and Ride Station has the role of allowing transfers from private cars to the monorail. Therefore, a large parking lot is constructed next to the station.

The area along Metro Line-3 is in the midst of continued residential and commercial development, which could create difficulty in securing land for a parking lot. For this reason, parking area needs to be minimized. One solution is to build a multilevel parking lot. In such case it is also important to avoid passengers' resistance to vertical movement. that would occur at the connecting point between the station and the parking lot. A direct connection from the station concourse by deck or bridge to the multilevel parking lot is recommended. A conceptual image of a Park and Ride Station is shown below.



Source: JICA Study Team

Figure 7.39 Representative example of a Park and Ride Station

(4) Land Acquisition for Intermodal Facilities

The land acquisition for the Intermodal Facility will only be required at the Nuevo Chorrillo Station and the Vista Alegre Station. The scale of the facilities is calculated as explained above in 7.7.1(2)2). At the Arraijan Mall Station, the Intermodal Facility will be included in the development plan for the shopping mall. Therefore, land acquisition will not be required for the monorail station. In addition, at the Ciudad del Futuro Station, the required area for the Intermodal Facility is included as part of the Depot area.

Regarding land acquisition, the minimum required land area should be selected that is within a short walking distance from the station.

The required land for the two Intermodal Facilities and their possible sites are shown in the photos below. The facilities should be constructed to minimize space, for example by constructing a multilevel structure for the parking area.

Nuevo Chorrillo Station (3,720m^2) Vista Alegre Station (4,200m^2+Access Road)

Source: Illustrated by JICA Study Team based on Satellite Image

Figure 7.40 Target Area for Land Acquisition

On the other hand, at the Ciudad del Futuro Station, the parking lot is constructed at the ground level. After phase-2 enters into operation, the intermodal function of this station will be reduced. At that time, a large parking lot will not be needed and part of it will be shifted to other land use, for example, residential area. For this reason, a large parking structure should not be constructed in this area.

7.8 Depot

7.8.1 Depot Size and Location

(1) Depot Size

In addition to stabling tracks, maintenance workshops, car washing facilities, tire exchange facilities, etc. for stabling and maintenance of the monorail cars, an administration building housing the OCC (operation control center) for the entire Metro Line-3, a substation, warehouse and other facilities will be included in the depot.

The number of train sets required, based on the demand forecast up to 2050, is 26 sets in 2022 (first year of operation). Subsequently, when opening of there future station is taken into account, the number of train-sets becomes 32. The train sets are all 6-car sets. Of these, 2 train sets will stable at Albrook Station at night, 1 train set at Panama Pacifico Station and 1 train set at Nuevo Chorrillo Station. Further, in preparation for future line extension, space will be secured in the depot for stabling tracks for an additional 10 train sets. Taking into account the space for other required facilities and equipment, the size of the land for the depot will be approximately 10 hectares.

(2) Depot Candidate Sites

1) Preconditions and Candidate Sites

Regarding the depot location, the METI study proposed a vacant lot along the Autopista route in Nuevo Arraijan (Candidate site-3 noted below). In this study, in addition to this vacant lot, 3 additional locations with sufficient space close to the route are suggested, making a total of 4 candidate sites.

Source: JICA Study Team

Figure 7.41 Depot Candidate Sites

<u>Candidate site-1 Canal western shore</u>

The ACP property is located on the western shore of the canal, currently used to deposit dredged soil and sand. The envisioned depot location would be along the 4th bridge approach road.

Candidate site-2 Arraijan

Vacant land on the northern side of the Arraijan Xtra (supermarket), located at a higher elevation than the main line. The land is not level, so land preparation would be required.

Candidate site-3 Nuevo Arraijan (along Autopista)

Vacant land proposed in the METI study. It is located on the western side of the Westland Shopping Mall along the Autopista.

Candidate site-4 Nuevo Arraijan (along Panamericana)

Land located on a hill on the west side of Nuevo Arraijan along the Panamericana. Land preparation would be required, but this site has the most available space among the candidate sites.

2) Depot Land Selection

Candidate sites are to be assessed based on the ease of construction and operation, and the final site for the depot will be selected accordingly. “Ease of construction” takes into account the securing of land with sufficient level area, as well as the degree of environmental impact, and “ease of operation” takes into account the establishment of an efficient operation plan and potential for future extension. In the following data, (A) indicates advantages and (D) indicates disadvantages. Candidate site-4 was selected as the depot site, based on the study results. Candidate site-4 is located along the Panamericana; it will allow the securing of the required area through land preparation, and provides a high degree of ease of operation.

Table 7.37 Assessment of each Candidate Site

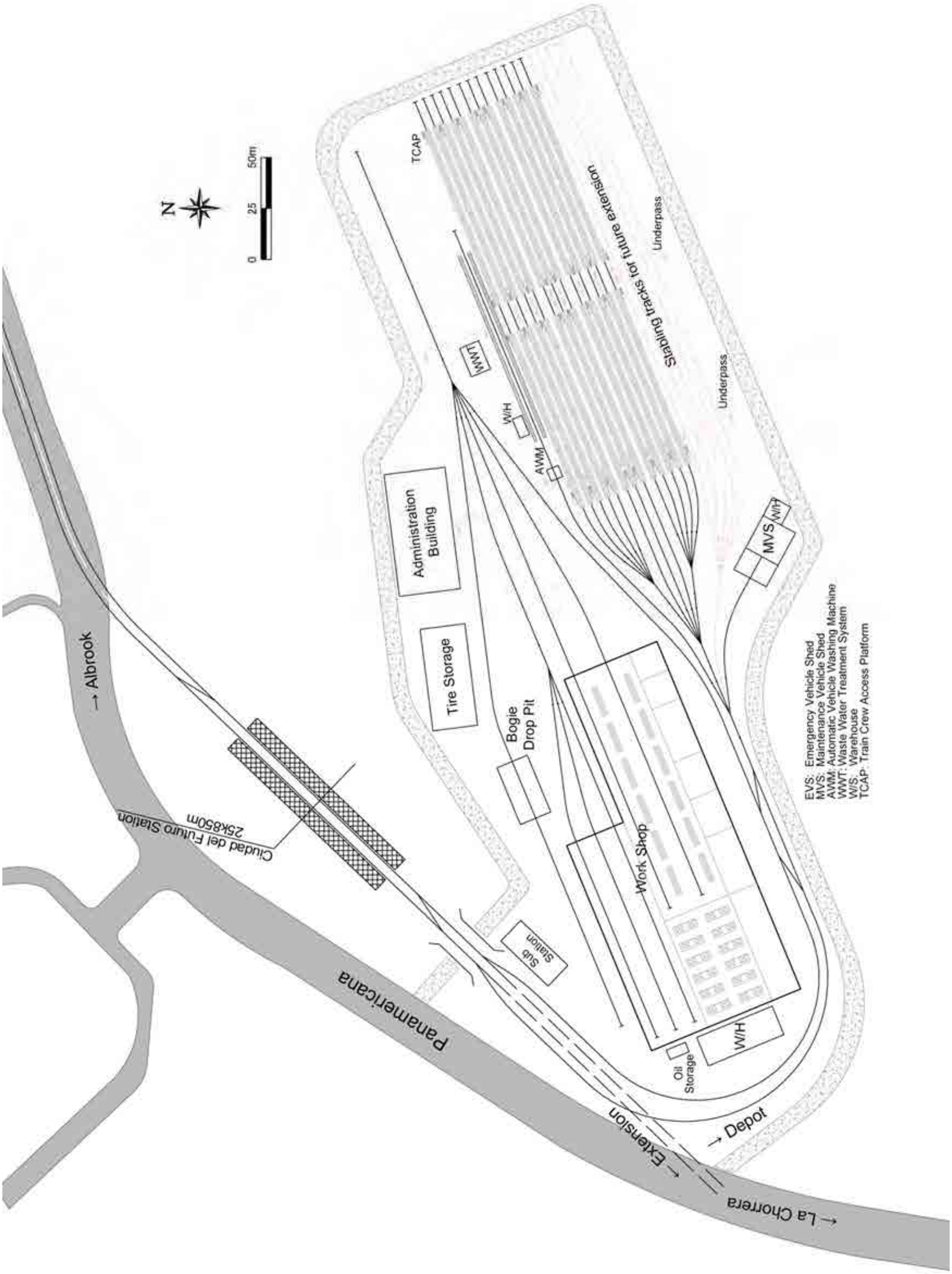
Candidate Site	Ease of Construction	Ease of Operation
1. Canal western shore	(A) Flat, level land with more land available than required. Property of ACP, so it would not require land acquisition from the private sector.	(A) Sufficient area to add stabling tracks in the event of future extension of the route.
	(D) An area for depositing earth and sand, and may potentially incur costs for foundation improvement to build a depot.	(D) Far from Nuevo Arraijan, where there is a high demand during the morning peak, so is not efficient.
2. Arraijan	(A) The land is at a high elevation, so no worries about flooding.	(A) Located nearly in the center of the route, so is superior to the site on the west shore of the canal in terms of train operation efficiency.
	(D) The eastern side of the land is a valley which would require large-scale preparatory construction. It may possibly be a man-made landfill, so there is potential that foundation improvement will also be necessary.	(D) Distance and difference in height from main line would require a long and complex approach track. It would also be difficult to secure space for car stabling in the event of future extension.
3. Nuevo Arraijan (Autopista)	(A) Used as a yard for construction material as of 2013, with 8.2ha of land available for sale. Land is pre-graded making it flat and level.	(A) Located on the west side of the route, where there is a large demand during morning peak hour, which allows for efficient operation of trains from the early morning.
	(D) Land ownership rights are currently in dispute, so there is a risk involved in purchasing the land.	(D) Distant from the main line requiring an approach track of approximately 2km, so it is not efficient.
4. Nuevo Arraijan (Panamericana)	(A) Land preparation would provide the largest area of available land among the candidate sites. Land is at a high elevation, so no worries about flooding.	(A) Construction could be carried out adjacent to the terminal station, making for an efficient, short approach track. Located on the west side of the route, where there is a large demand during morning peak, it allows for efficient operation of trains from the early morning.
	(D) Located on a hill, so large-scale preparatory construction would be necessary.	

Source: JICA Study Team

7.8.2 Depot and Workshop

(1) Depot Layout

The depot layout is shown in Figure 7.42



Source: JICA Study Team

Figure 7.42 Depot Layout

(2) Depot Internal Line Facilities

The roles, functions and number of tracks for each line facility inside the depot are shown in Table 7.38.

Table 7.38 Roles, Functions and No. of Tracks for each Line Facility

Line Facility	Role and Function	No. of Tracks
Approach track	The approach track is the track connecting the main line and the depot and is used for trains and maintenance vehicles to enter and exit the depot. In addition, the approach track should consist of multiple tracks to allow for efficient entry and exit. Of the 2 approach tracks, the exterior track will turn out from the main line, then go through a grade separation from the main line and enter the depot after descending down to ground level.	2 tracks
Stabling track	The stabling track is a track for stabling cars. 2 trains are stabled on each stabling track.	13 tracks (18 tracks in the future)
3-day inspection track	A track for carrying out 3-day inspections, located inside the workshop.	2 tracks
3-month inspection track	A track for carrying out 3-month inspections, located inside the workshop.	1 track
Minor overhaul track	A track for carrying out minor overhauls, located inside the workshop.	1 track
Major overhaul track	A track for carrying out general overhauls, located inside the workshop.	1 track
Tire exchange track	The tire exchange track is a track used during inspection and replacement of rubber tires. A bogie drop pit, which serves as a work area for tire inspections and replacement, is installed on the tire exchange track.	1 track
Car washing track	The car washing track is a track for carrying out car washing. Platforms, which will serve as scaffolding during washing, are installed on both sides of one section of the washing track. An automatic car washing machine is installed on one of the two washing tracks.	1 track

Source: JICA Study Team

(3) Workshop

The workshop is a facility for carrying out car inspections and repairs. The areas inside the workshop can be broadly divided into a light maintenance shed and a heavy maintenance shop.

3-day inspections and 3-month inspections are made of the car condition and functions with the chassis still in place, in the light maintenance shed, which is also utilized for ad-hoc inspections when 3-day and 3-month inspections are not being carried out.

The heavy maintenance shop is a location for carrying out minor and major overhauls where the cars are disassembled for maintenance. The work area is divided by the type of maintenance and consists of an assembly shop, bogie shop, heavy components shop, electronics shop, air room, etc. It is also used as a stabling track when minor and major overhauls are not being done.

Workshop layout is shown in Figure 7.43.

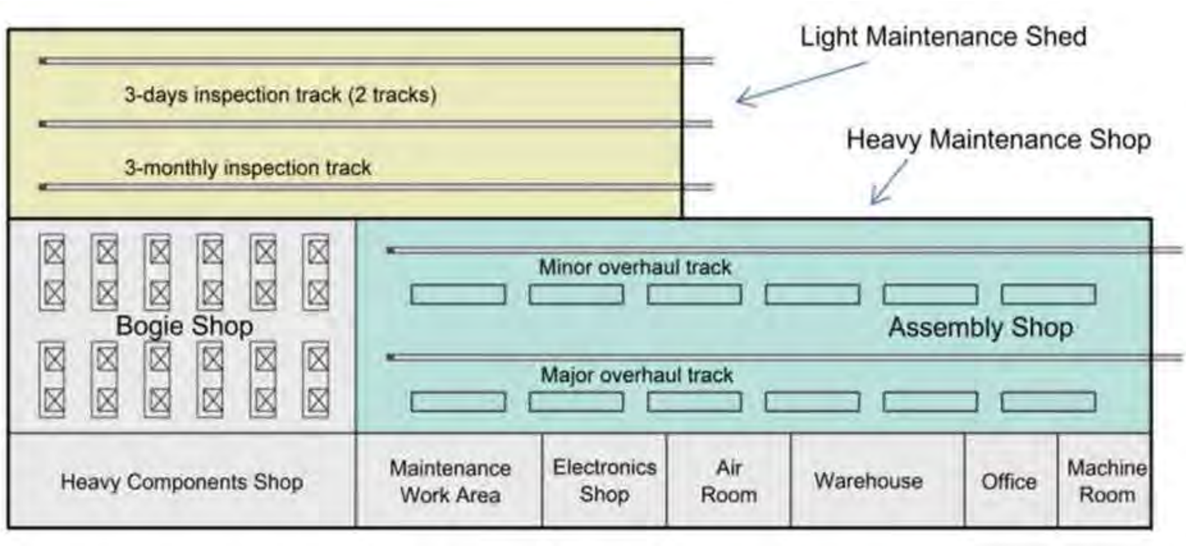


Figure 7.43 Workshop Layout

(4) Administration Building

In addition to holding the function as a headquarters, the administration building also houses the OCC (operation control center) and depot control room, which carry out operations management for the main line and for the trains in the depot. The facilities located in the administration building are shown below.

- Headquarters
- Office
- OCC (operation control center)
- Depot control room
- Electrical equipment room
- Signaling equipment room
- Communications equipment room
- Conference rooms
- Cafeteria and break rooms
- Nap rooms and locker rooms
- Visitor space
- Security office

(5) Maintenance Vehicle Shed

The shed designed for the transport, storage and stabling of maintenance vehicles and materials which are used to do maintenance on the beams and circuits after the monorail stops operating. The maintenance vehicle shed can stable 3 maintenance vehicles and is equipped with a traverser at the front of the shed to allow maintenance vehicles to switch tracks.

(6) Other Facilities

In addition to the above facilities, warehouses, wastewater treatment system, oil storage, substation and emergency vehicle shed will also be established.

7.8.3 Maintenance Facility

The list of the equipment used in maintenance work is shown below according to work location.

Table 7.39 Equipment List

Work Location	Equipment	Qty.
3-day Inspection Area	Access platform	2 units
	ATC/TD simple testing system	1 system
	Nitrogen gas filling device	1 system
3-month Inspection Area	Movable train dust collector	2 units
	Scissor lift	2 units
	Scaffolding for air conditioner & roof maintenance	3 units
	Train performance tester	1 system
	Elevating platform	2 units
Heavy maintenance shop <Assembly shop>	Overhead traveling crane（10t/2.8t）	2 systems
	Under-frame component dismantling trolley	2 units
	Under-frame component dismantling trolley	1 unit
	Car body support stand	24 units
	Bogie lifting beam	1 set
	Scissor-lift	2 units
	Fence for air conditioner maintenance	1 set
Heavy maintenance shop <Bogie shop>	Bogie maintenance stand	12 units
	Bogie air blowing booth	1 unit
	Bogie Lifting Beam	2 sets
	Gear unit stand	24 units
	Pressing force measuring device for guide/stabilizing tire	1 unit
	AC argon arc welding machine	1 unit
	Magnetic flaw detector	1 unit
	Hydraulic press brake	1 unit
	Jigs	1 set
Heavy maintenance shop <Heavy components shop>	Battery charging & discharging unit	1 unit
	Rotating machine air blowing unit	1 unit
	Rotating machine testing bench	1 unit

	Traction motor disassembling jig	1 set
	Air compressor testing bench	1 unit
Heavy maintenance shop <Electronics shop>	VVVF test bench	1 unit
	ATC/TD simple testing system	1 system
	Dielectric testing unit	1 unit
	Train insulation testing unit	1 unit
Heavy maintenance shop<Air room>	Small parts washing & air blowing unit	1 unit
	Electric valve testing stand	1 unit
	Pressure gauge	1 unit
	Ultrasonic cleaning unit	1 unit
Bogie drop pit and tire storage	Bogie drop	1 unit
	Car body support stand	1 unit
	Tire rack	192 units
	Running tire changer	1 unit each
	Temporary bogie	1 unit
	Bogie stand	1 unit
	Overhead traveling crane (500 kg)	1 system
	Nitrogen gas filling device	1 system
	Air compressor	1 unit
	Hand Lifter	4 units
Car washing track	Automatic car washing machine	1 set
	Scaffolding for monorail car head cleaning	1 set
Maintenance Vehicle Shed	Maintenance vehicle	3 units
	Traverser	1 unit
	AC arc welding machine	1 unit
	Jigs	1 set

Source：JICA Study Team

The pictures and purpose of major equipment used in maintenance work are shown below according to work location.

(1) 3-day Inspection Area

1. Access platform		2. Other
Qty.: 2 units Stairs used to enter and exit the monorail cars.		• ATC/TD simple testing system (1 system): System used for testing ATC/TD functions • Nitrogen gas filling device (1 system): Equipment used to fill running tires as well as guide/stabilizing tires with nitrogen gas.

Source：JICA Study Team

(2) 3-month Inspection Area

1. Movable train dust collector		2. Scissor lift	
Qty.: 2 units Device which uses compressed air to blow away and vacuum dust from the bottom of the car, bogie and skirt interior.		Qty.: 2 units Machine used for inspections, maintenance and other work at high elevations, which is composed of a work platform, elevator device and other components.	
3. Scaffolding for air conditioner & roof maintenance		4. Other	
Qty.: 3 units Work scaffolding used for inspection and maintenance of roof and air conditioning equipment.		• Train performance tester (1 system): Device which automatically tests various vehicle functions. • Elevating platform (2 units): Stairs used to enter and exit the monorail cars.	

Source：JICA Study Team

(3) Heavy maintenance shop

1. Overhead traveling crane (10t/2.8t)

Qty.: 2 systems

Overhead crane used to lift and transport vehicles from beam, and for maintenance of vehicle parts.

＜Assembly shop＞

2. Under-frame component dismantling trolley

Qty.: 2 units

Specialized trolley for attaching and detaching the components located under the frame.

3. Shunting unit

Qty.: 1 unit

Compact shunting unit used when uncoupling priority inspection vehicles.

4. Car body support stand

Qty.: 24 units (for 12 car bodies)

Support stand for supporting car bodies raised off of the beam.

5. Other

- Bogie lifting beam (1 set): Track beam that can be attached and detached at the entrance to the heavy maintenance shop.
- Scissor-lift (2 units): Machine used for inspections, maintenance and other work at high elevations, which is composed of a work platform, elevator device and other components.
- Fence for air conditioner maintenance (1 set): Stand for checking air conditioner equipment function.

＜Bogie shop＞

6. Bogie maintenance stand

Qty.: 12 sets

Bogie stand for carrying out maintenance of bogie equipment.

7. Bogie air blowing booth

Qty.: 1 unit

Equipment for washing bogie frame and other large parts with high pressure steam.

8. Bogie Lifting Beam

Qty.: 2 sets

Track beam with narrowed track width to reduce tire pressing force in order to allow for easier removal of bogie equipment from track using a crane.

9. Other

- Gear unit stand (24 units): Decelerator stand.
- Pressing force measuring device for guide/stabilizing tire (1 unit): Equipment for measuring guide/stabilizing tire pressing force.
- AC argon arc welding machine (1 unit): Used for welding aluminum materials (car body, etc.)
- AC arc welding machine (1 unit): Used for welding standard steel materials.
- Magnetic flaw detector (1 unit): Detector used to inspect cracks in welded segments, etc.
- Hydraulic press brake (1 unit): Used when removing bearings and gears for running tires, decelerator, etc.
- Jigs (1 set): Various work tools.

＜Heavy components shop＞

10. Battery charging & discharging unit

Qty.: 1 unit

Equipment which carries out charging and discharging for maintenance of car vehicle batteries.

11. Other

- Rotating machine air blowing unit (1 unit): Equipment which is used for air blasting of rotating machines.
- Rotating machine testing bench (1 unit): Equipment which is used for rotation testing of rotating machines.
- Traction motor disassembling jig (1 set): Equipment used for assembly and disassembly of traction motor.
- Air compressor testing bench (1 unit): Testing equipment used to check air compressor performance.

＜Electronics shop＞

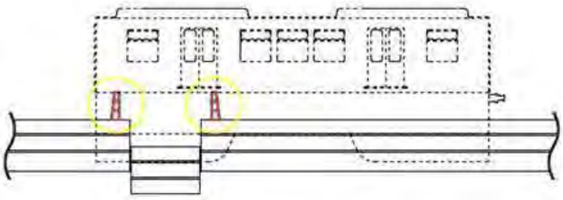
- VVVF test bench (1 unit): Tester for control system component instruments.
- ATC/TD simple testing system (1 system): System used for testing ATC/TD component instruments.
- Dielectric testing unit (1 unit: Measurement device
- Train insulation testing unit (1 unit): Insulation testing unit for standard electrical circuits

＜Air room＞

- Small parts washing & air blowing unit (1 unit): Equipment for carrying out air blasting of small parts.
- Electric valve testing stand (1 unit): Tester for checking performance of air control valves.
- Pressure gauge (1 unit): Device for measuring tire pressure.
- Ultrasonic cleaning unit (1 unit): Cleaning unit for cleaning small precision parts.

Source：JICA Study Team

(4) Bogie drop pit and tire storage

<table>
<tr><td colspan="4">1. Bogie drop</td></tr>
<tr><td colspan="4">Qty.: 1 unit</td></tr>
<tr><td colspan="4">Hydraulic equipment for attaching and detaching bogie from car body. Used for inspection and maintenance work for running tire replacement and bogie mounted components.</td></tr>
<tr><td colspan="4">  </td></tr>
<tr><td colspan="4">2. Car body support stand</td></tr>
<tr><td>Qty.: 1 unit
Support stand that supports car body on track beam when car body is removed from bogie.</td><td></td><td colspan="2"></td></tr>
<tr><td colspan="2">3. Tire rack</td><td colspan="2">4. Running tire changer</td></tr>
<tr><td>Qty.: 192 units
(8 train sets)
Storage rack for running tires and guide/stabilizing tires.</td><td></td><td>Qty.: 1 unit each
Equipment used to attach and detach running tires and guide/stabilizing tires.</td><td></td></tr>
<tr><td colspan="2">5. Temporary bogie</td><td colspan="2">6. Other</td></tr>
<tr><td>Qty.: 1 unit
Mounted to car body in place of removed actual bogie and used for transporting car body inside shop.</td><td></td><td colspan="2">• Bogie stand (1 unit): Temporary stand for disassembled bogie. Also used as work platform ad-hoc bogie maintenance.
• Overhead traveling crane（500 kg） (1 system): Used to lift the bogie from and lower on to the bogie drop.
• Nitrogen gas filling device (1 system): Equipment used to fill running tires as well as guide/stabilizing tires with nitrogen gas.
• Air compressor (1 unit): Air supply for pneumatic tools and air blasting.
• Hand Lifter (4 units): Portable support stand for tire loading and unloading.</td></tr>
</table>

Source：JICA Study Team

(5) Car washing track

1. Automatic car washing machine		2. Scaffolding for monorail car head cleaning	
Qty.: 1 unit		Qty.: 1 set	
Equipment for automatically washing vehicle body panels.		In addition to fixed platforms installed on both sides of the washing track, work platforms that can be attached and removed freely for hand washing of car body front and back parts in front of and behind stop position.	

Source：JICA Study Team

(6) Maintenance Vehicle Shed

1. Maintenance vehicle			
Qty.: 3 units			
Specialized maintenance vehicle for inspecting beam and electrical parts around the beam. Maintenance vehicle used for transport of heavy, long, etc. loads and maintenance work.			
2. Traverser		3. Other	
Qty.: 1 unit		• AC arc welding machine (1 unit): Used for welding standard steel materials. • Jigs (1 set): Various work tools.	
Device for transferring maintenance vehicle to different tracks.			

Source：JICA Study Team

7.9 Power Supply

7.9.1 Power Supply System in Panama

(1) Present Power Supply condition in Panama

Electric power in Panama is supplied by power generation companies, a transmission system company and distribution companies. Several power generation companies generate electricity and send it to a power transmission company named "EMPRESA DE TRANSMISSION ELECTRICA, SA (ETESA)" and this company controls the nationwide transmission line system in Panama.

ETESA's transmission line system has a trunk line network with the highest voltage of 230kV under which a 110kV network is formulated as shown in the Figure 7.44. The voltage of 110kV is transformed to lower voltages of 34.5kV and 13.8kV for ordinary consumers. These voltages are commonly used in Panama. Other voltages, including 40kV and 12kV, are used in some areas, but there is no plan for new facilities with these voltages.

Power supply to public consumers is performed by two distribution companies: "ELECTRA NORTE S.A." in the eastern area of Panama City, and "GAS NATURAL FENOSA (Gas Fenosa)" in the west.

The power supply for Metro Line-3 will be done by Gas Fenosa for the whole section.

Reliability of ordinary power supply for consumers is not high, and power stoppages of the ordinary supply sometimes happen even in the Panama City area. The power supply in the project area is not necessarily stable for a mass railway transit system.

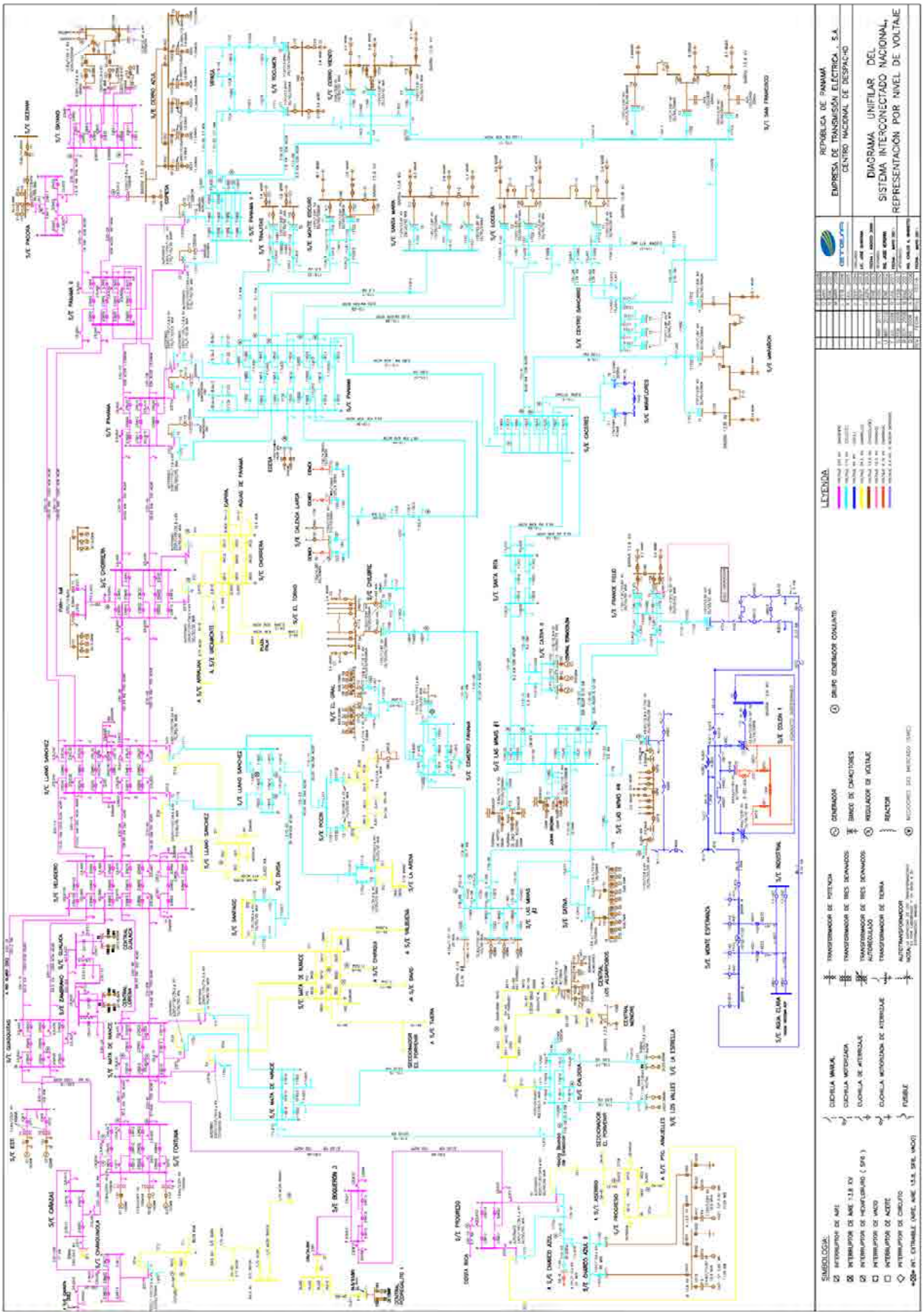
(2) Power Supply Plan for Metro Line-3

The JICA Study Team had a meeting with Gas Fenosa about the power supply for Metro Line-3. According to their information about the power receiving points, power can be received at Albrook, at the central area of the Line and at the end of the Line around the depot. Although, currently, there is no power source to satisfy the power demand of Line-3 at these locations, Gas Fenosa can prepare the power sources in response to a request from SMP.

Gas Fenosa has a plan to develop a new substation in Burunga and is preparing land acquisition for the project, according to the information given in the meeting. The new substation will be directly connected to ETESA's 230kV transmission line system for 34.5kV and 13.8kV. The necessary voltage and capacity can be incorporated into the new substation. Since the construction is scheduled for 2014-2015, the substation can supply the power to Line-3 from its commissioning stage.

The reliability of the power source will be high because it is directly branched from the 230kV transmission line. Power reception has four power sources with two directions (substation) and doubled lines, and the substation will be equipped with new reliable devices to provide sufficient reliability. The electric power for Metro Line-3 will be supplied by exclusive lines from this substation.

The location of the substation is shown in the Figure 7.45. The distance to the substation from Metro Line-3 is less than 2km, and the short distance will be advantageous for line reliability and construction cost.



Source: SMP

Figure 7.44 ETESA Transmission System

Source: Gas Fenosa

Figure 7.45 Construction Site for Burunga Substation

7.9.2 Transmission Line System

(1) Transmission Line Voltage

The Project requires large electric power. It is estimated that the power demand is 25MVA (traction power 34 MVA, utility power 6MVA) in 2020 and 30MVA (traction power 23MVA, utility power 6MVA) in 2050. If the final target is set at 50MVA, considering some margin, the required current capacity and suitable section cable with enough current ratings for 13.8kV and 34.5kV will be as follows:

- 13.8kV 2,090A XLPE 630mm2x2x3 (trefoil) 1,110Ax2= 2,220A
- 34.5kV 840A XLPE 400mm2x1x3 (trefoil) 840A

In the case of dividing the load in two at the middle point, these values will be as follows:

- 13.8kV 1,050A XLPE 630mm2x1x3 (trefoil) 1,110A
- 34.5kV 420A XLPE 150mm2x1x3 (trefoil) 470A

The actual cable section may be wider than the above calculations due to voltage drop.

Concerning the cost, it is difficult to directly compare costs because of the difference in cable voltage, but the wider section cable is costly and it seems the higher voltage would be advantageous even when including the cost of the connecting device.

For the Project, the 34.5kV transmission line is advantageous.

(2) Transmission Line Structure and Recommended Plan

The transmission line structure was studied assuming the use of the voltage from the 34.5kV system based on the power supply information received from Gas Fenosa.

The following four alternatives were studied and Plan 2 is recommended for the Project.

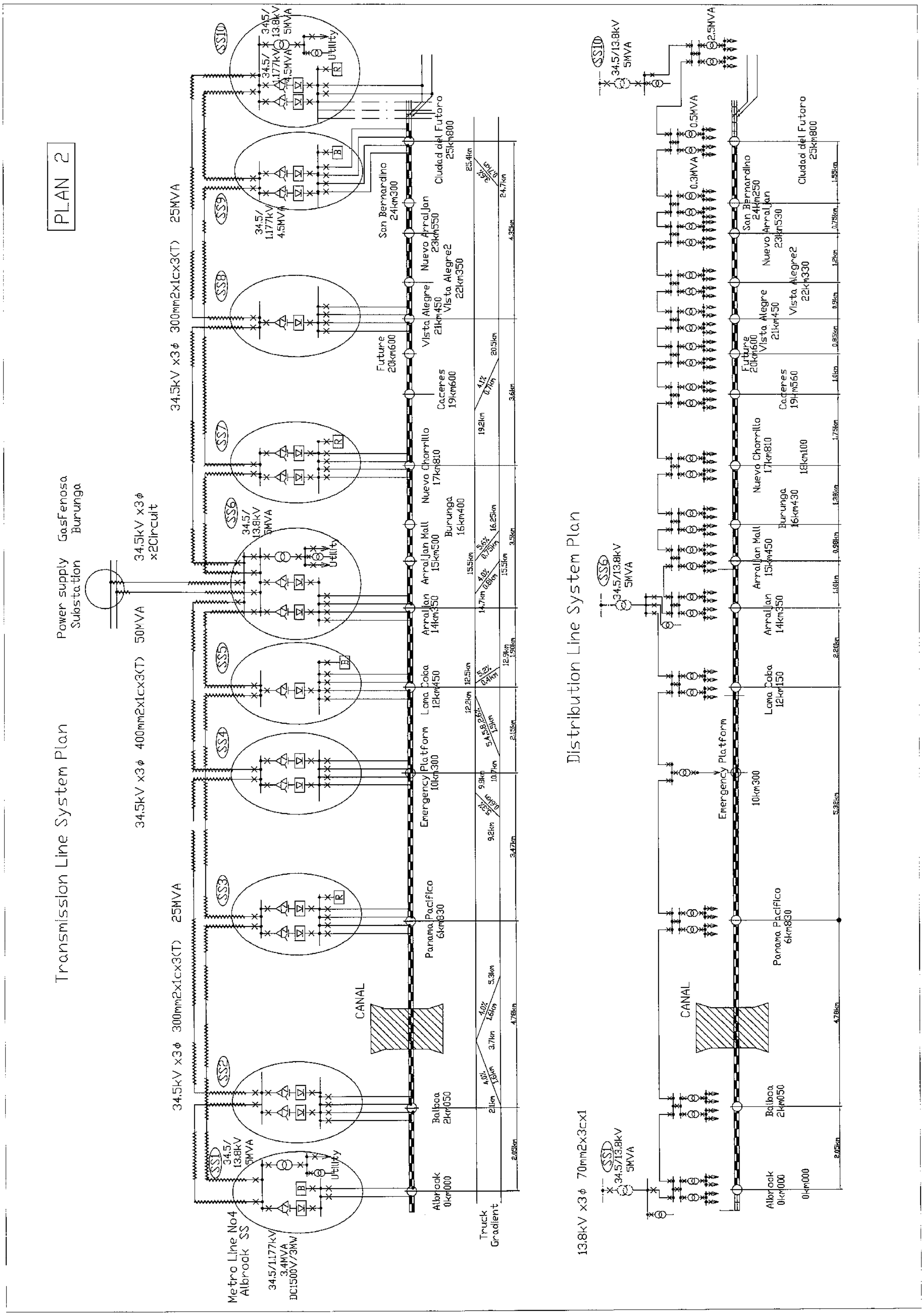
- Plan 1: 34.5kV both end reception with one loop supply system
- Plan 2: 34.5kV only one middle point reception with two loop supply system
- Plan 3: 34.5kV only one middle point reception with two standby line supply system
- Plan 4: 13.8kV three point reception, middle and both ends, with two single loop system

Regarding the cost, considering the number of cables, the voltage and the cost of switchgears, Plan 4 is most economical; on the other hand the cable section is big and needs three-receiving points, which raises the cost for cables and the connection cost with the power company.

Plan 3 is the most reliable, and the easiest to maintain, although the cost is higher than the others due to the number of switchgears.

Plan 2 is recommended for the Project because it is reliable enough with reasonable cost.

Figure 7.46 shows the drawing of Plan 2. The voltage drop calculation for Plan 2 is shown in Table 7.40 for the case of long-loop and considering the worst case.



Source : JICA Study Team

Figure 7.46 Transmission Line System Plan

Table 7.40 Transmission Line Voltage Drop Table

34.5kV Transmission Lines for Traction Substation
Calculation of Voltage Drop

NO.	Electric System: Phase: Number of Cables φ	w	Voltage E (V)	Frequency f (Hz)	Section	Load: Circuit Capacity P	Unit	Power Factor cosθ	Efficiency λ	Circuit Current I (A)	Cabling: Circuit Length L (m)	Type: Kind of Cables	Size (mm2)	No. of Cable N	Current Carrying Capacity Iρ (A)	Line Constants: Resistance /km Ra (Ω/km)	Reactance /km Xa (Ω/km)	Impedance: Resistance R=Ra*L÷n/N*1000 (Ω)	Reactance X=Xa*L/N*1000 (Ω)	Voltage drop e (V)	Voltage drop δ=e/E*100 (%)	Note
CASE1																						
SS5 to SS6 Worst case																						
					SS-6																	
1	3	3	34500	60	~SS-5	39,000	kVA	0.9	1	725	2,050	33kV XLPE-1C	300	1	740	0.079	0.136	0.1623	0.2780	335.6	0.97	
					SS-5																	
2	3	3	34500	60	~SS-3	36,000	kVA	0.9	1	669	5,850	33kV XLPE-1C	300	1	740	0.079	0.136	0.4632	0.7933	883.7	2.56	
					SS-3																	
3	3	3	34500	60	~SS-1	30,000	kVA	0.9	1	558	6,750	33kV XLPE-1C	300	1	740	0.079	0.136	0.5345	0.9153	850.5	2.47	
					SS-1																	
4	3	3	34500	60	~SS-2	27,000	kVA	0.9	1	502	2,150	33kV XLPE-1C	300	1	740	0.079	0.136	0.1702	0.2915	243.7	0.71	
					SS-2																	
5	3	3	34500	60	~SS-4	21,000	kVA	0.9	1	390	8,350	33kV XLPE-1C	300	1	740	0.079	0.136	0.6611	1.1323	735.3	2.13	
					SS-4																	
6	3	3	34500	60	~SS-6	15,000	kVA	0.9	1	279	4,150	33kV XLPE-1C	300	1	740	0.079	0.136	0.3286	0.5627	261.4	0.76	
																			Total	2974.6	8.6	

Permissible conducter temperature : 90℃
Ambient tempereture : 40℃
Formura for Voltage Drop : $e = K*I*(R*COS\theta + X*SIN\theta)$
(K=2: 1 φ, K=√3: 3 φ)

Source : JICA Study Team

The power load of a traction substation fluctuates widely and the load of the rectifiers generates harmonics. Exclusive power reception is desirable not only to protect ordinary customers from the fluctuation and harmonics, but to also avoid such influence from ordinary consumers, whose management over their power use is insufficient.

7.9.3 Traction Power Feeding System Plan

(1) Traction System Structure

Power feeding to the rolling stock is performed by DC 1500V system, and the voltage range is 1900V maximum voltage and 1000V minimum voltage following the IEC limit.

A doubled system should be provided for the power feeding structure to ensure high reliability, which enables normal train operation even if one device fails. If two or more devices fail at the same time, limited train operation is required.

The distance between substations is decided based on the rectifier capacity and the line drop.

Two system plans were considered for keeping the feeding system voltage within a range described in the first phase of the section: one is a concentrated system and the other is a separated system.

In the separated system plan, standard capacity substations are distributed at regular intervals. Each substation has one set of rectifiers, except for the substations located at both ends where there are two sets of rectifiers to prevent large voltage drop that would be caused by a failure of the whole substation.

In the concentrated system plan, substations are constructed with two rectifier sets. Stoppage of all substations will not happen in this case.

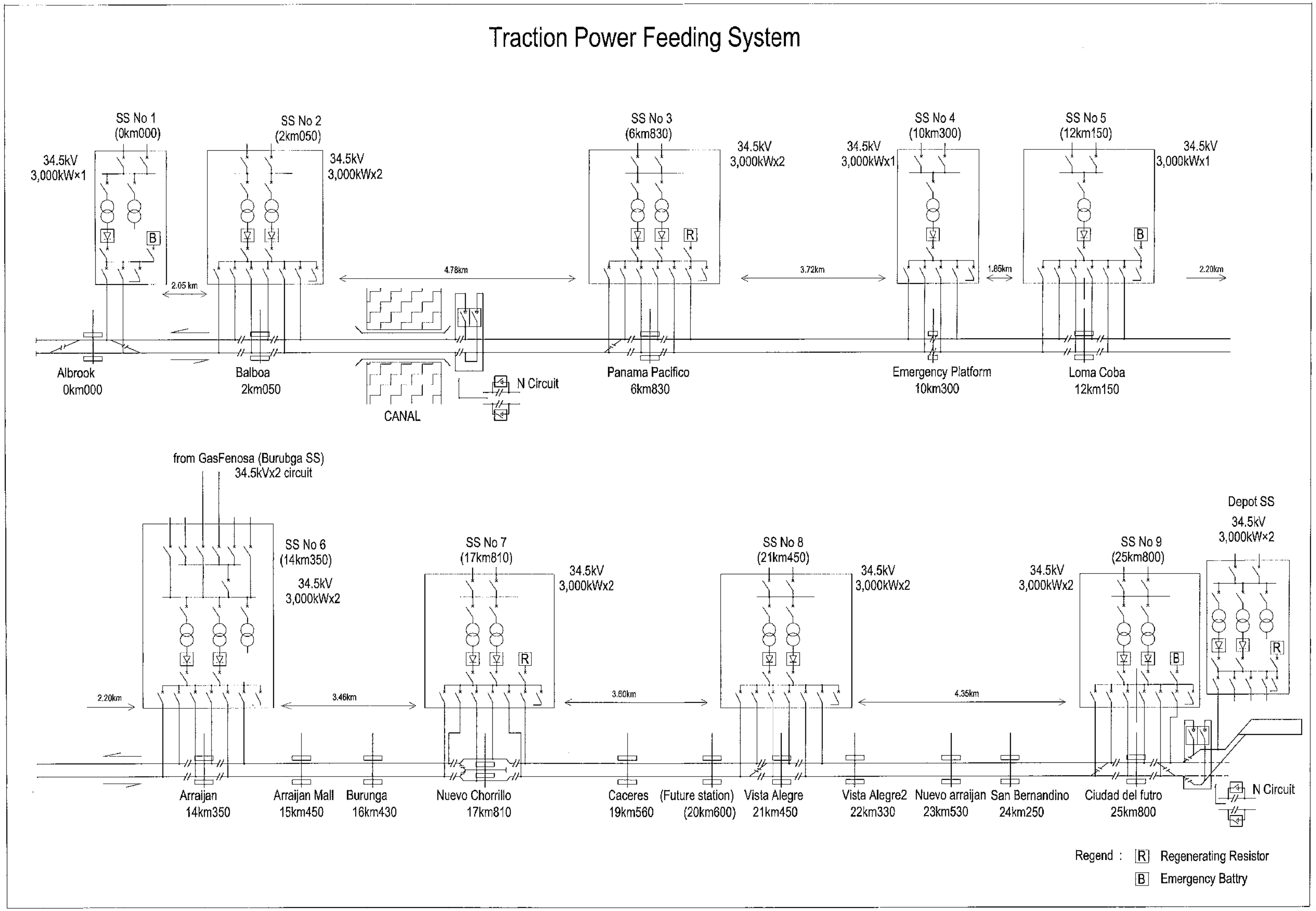
Both system plans can keep the feeder voltage within the defined range in case of failure of one set of devices in a system. The feeding voltage for normal operation in the concentrated system is lower than that of the separated system. In addition, in case of feeder stoppage from failure in the contact line, the separated area for the concentrated system would be longer than that of the separated system, which would cause wider area stoppage.

The cost of the concentrated system is lower than that of the separated system because of the small number of receiving equipment, and the maintenance work is easier. However, the separated system is recommended considering its reliability.

From the view of maintenance and security, SMP requested that the substation be located in the station area. All the substations are planned to be construct in the station area. The distances between adjacent substations are not evenly spaced, therefore the substation interval and capacity cannot be standardized. Substation interval and capacity were decided based on the calculation of rectifier capacity and voltage drop as described below.

The selected feeding system diagram is shown in the Figure 7.47

Load estimations for the year when operations begins and for 2050 are shown in Table 7.41. The feeding voltages for normal case and emergency case are shown in Table 7.42. These estimates were made based on the feeding system diagram decided upon and the train operation plan.



Source: JICA Study Team

Figure 7.47 Feeding System Diagram

Table 7.41 Power Consumption by Traction

Power consumption for traction　　　PANAMA METRO LINE No 3

2020-2050-　　P-consumption rate　100 kwh/1000t･km (includes utility power)
P. weight　65 kg/parson　TC-car weight(t)　27 (t)　M-car weight(t)　26.5 (t)
Sch speed1　42 km/h　Sch speed2　33 km/h　Line Resistance(Ω/km)　0.027
(+ and -)

No of Cars		No of Pass.				
4	Cars		492	572	652	732
6			750	870	990	1112
8			1008	1168	1328	1492
	Conjestion	(person/m2	4	5	6	7

Car No /set (car/set)	Headway (Minutes)	Consp. Rate (Approx.) (kWH/kt-km)	Capacity Passengers par/m2	Car Weight (Ave.) (t)	1.Albrook service area 0.00 (km)	2.Balboa 2.05	3.Panama Pacifico 6.83	4.Emergency Platform 10.30	5.Loma Coba 12.15	6.Arrijan 14.35	7.Nuevo Cholrrilo 17.81	8.Vista - Alegre 21.45	9.Cuidad EL.Futro 25.80	Ciudad El Futro(2) 25.85	Depot+ 26.35 (26.1)	Total Lgn. (km)	Total (kW)	(kVA)	Reference total transportation Capacity
6	3.3 (3min20S) (18train/h) at y. 2020	100	6	37.39 224.4	1.03 836.2	3.42 2786.0	4.13 3365.3	2.66 2170.1	2.03 1652.0	2.83 2308.8	3.55 2896.2	4.00 3259.2	2.20 1794.8 2019.2	0.3 224.4		26.1	21292.9	Pf=0.95 22414	Pass. No per Direction 18000.0
6	5.4 (11train/h) at y. 2020	100	6	37.4 224.4	1.0 511.0	3.4 1702.6	4.1 2056.5	2.7 1326.2	2.0 1009.6	2.8 1410.9	3.6 1769.9 2269.5 (*)	4.0 1991.7	2.2 1096.8 1233.9 (**)	0.3 137.1		26.1 Partial O.	13012.3 18113.9	13697 19067	11000.0
6	2.7 (2min40Sec) (22train/h) at y. 2050	100	6	37.4 224.4	1.0 1022.0	3.4 3405.1	4.1 4113.1	2.7 2652.3	2.0 2019.2	2.8 2821.8	3.6 3539.7	4.0 3983.5	2.2 2193.6 2467.9	0.3 274.2		26.1	26024.6	27394	22000.0
6	5 (5min.00sec) (12train/h) at y. 2050	100	6	37.4 224.4	1.0 551.9	3.4 1838.8	4.1 2221.1	2.7 1432.3	2.0 1090.3	2.8 1523.8	3.6 1911.5 2633.7 (*)	4.0 2151.1	2.2 1184.6 1332.6 (**)	0.3 148.1		26.1 Partial O.	14053.3 21428.7	14793 22557	11880.0
6	2 (120sec) (40train/h)	100	6	37.4 224.4	1.0 1379.8	3.4 4596.9	4.1 5552.7	2.7 3580.6	2.0 2725.9	2.8 3809.5	3.6 4778.7	4.0 5377.7	2.2 2961.4 3331.6	0.3 370.2		26.1	35133.2	Pf=0.95 36982	Pass. No per Direction 29700.0
6	2.4 (2min 20sec) (22train/h)	100	6	37.4 224.4	1.0 1149.8	3.4 3830.8	4.1 4627.2	2.7 2983.9	2.0 2271.5	2.8 3174.6	3.6 3982.2 4335.5 (*)	4.0 4481.4	2.2 2467.9 2776.3 (**)	0.3 308.5		26.1 Partial O.	29277.7 32885.2	Pf=0.95 30819 34616	Pass. No per Direction 24750.0
Substation Capacity (KW)					3000	3000 x2 set	3000 x2 set	3000	3000	3000 x2 set	3000 x2 set	3000 x2 set	3000 x2 set						

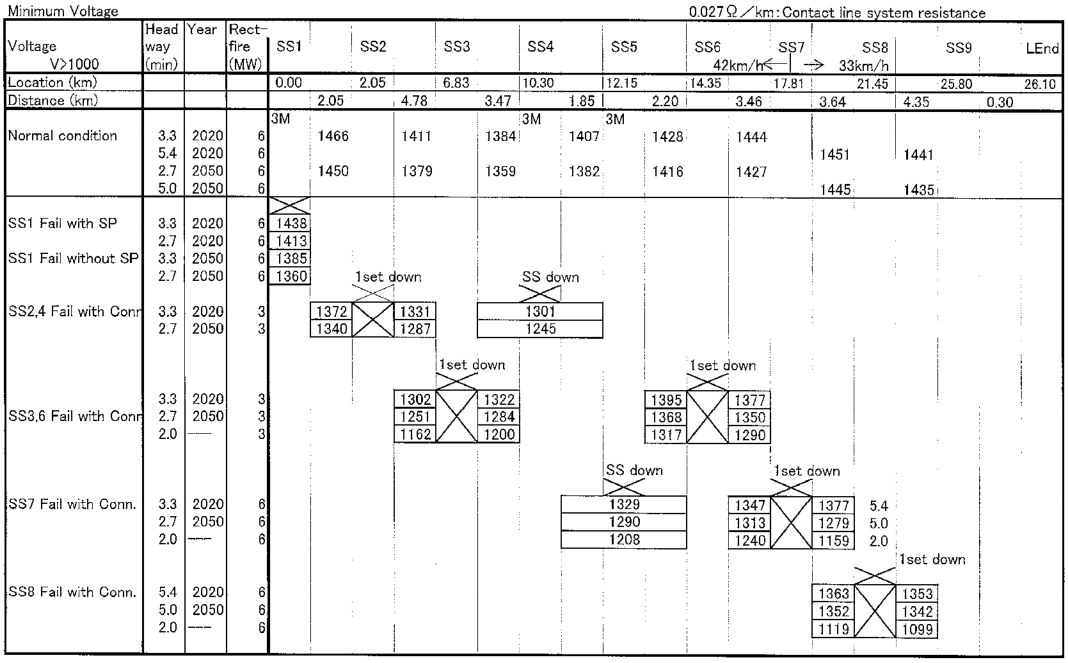
Note　* Proportional to service distance for each direction
** Add end direction load

Source: JICA Study Team

Table 7.42 Voltage Drop Calculation

Result of Voltage Drop Calculation in the DC Feeding System for Line No3

Minimum Voltage 0.027Ω／km: Contact line system resistance



Source: JICA Study team

(2) Main equipment in the Substations

Substations will be constructed mainly in station buildings. The structure of all the equipment should ensure that charged parts are not exposed; a shielded case or direct connection between equipment should be used.

1) Transformer

The transformer for the rectifier is a dried or molded type because of indoor installation and considering fire fighting characteristics. A gas insulation type is large and costly and is not recommended. The capacity of the equipment is 3000kW from the capacity calculation and the voltage is 34.5kV.

2) Rectifier

The rectifier set should be a 6-phase full wave rectification system to reduce the generation of harmonic. The rectifier set will satisfy overload ratings of 150% for 2 hours and 300% for 1 minute. For the cooling method, non-halogen, boiling, self-cooled type is recommended because of its fire prevention characteristics and less maintenance is required, although there are other types, such as the dry type with fan and the oil immersed self-cooled type. The wiring between the transformer and rectifier should be bus-duct type to prevent exposing the charged parts and the complexity of wiring. The 34.5kV system devices should be enclosed in the cubicle.

3) Re-generation Power Absorbing Devices

Re-generation Power Absorbing Devices (resistor type) should be installed at every two places.

4) Emergency Power Supply

The power supply system in Panama is not stable, and several power stoppages have occurred in the ordinary power supply. The Project plans to receive power from the most reliable system in Panama, but power stoppage could still possibly happen. According to the information received, this system experienced one stoppage in the last five years.

As a countermeasure, it is recommended that the above re-generating power absorbing system be replaced with a high-capacity battery compensating system in three places out of the five.

This system is expensive and may require careful handling because it was only recently developed and put in the market. Furthermore, since this equipment is a battery type, it may require periodical replacement and other special maintenance. This equipment has power absorbing characteristics, therefore it can replace the re-generating power absorbing device.

5) Breaker

Since the feeding section is long for one feeding circuit, a communication based linking breaking system should be introduced to ensure feeder protection in the case of extended feeding caused by overload or short circuit. Equipment using fiber optics in the telecommunication system will be suitable.

For the protection of the feeding circuit, a DC high-speed circuit breaker in a door-type grounded case should be used. For ease of maintenance, it will be equipped with a change-over type standby circuit breaker.

In the contact line system, a middle section is planned because the substations will be constructed in the station area and will be equipped with protective DC circuit breaker.

The standardization of equipment is preferable for the ease of maintenance and replacement in case of failure. Since almost all of the equipment for the Project will be imported, requiring a long time for re-purchases, stand-by or replacement equipment need to be prepared from the planning stage. The storage of electrical equipment under non-charged condition may create a problem. Therefore, the stand-by use of such equipment is preferable.

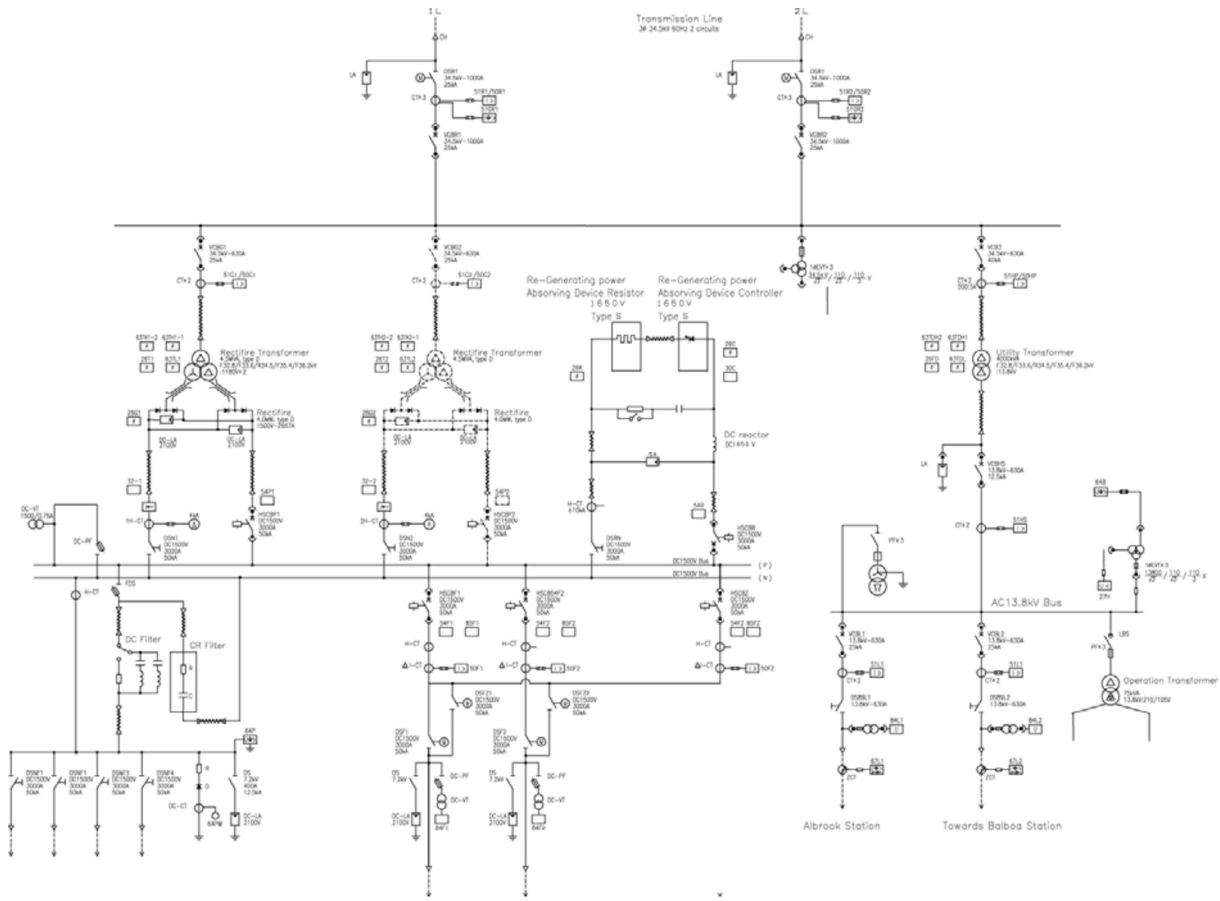
Figure 7.48 shows the connection of the substation based on the above analysis.

(3) Supervisory control system (Power SCADA)

The Supervisory Control and Data Acquisition system (SCADA) will be used for the control of the power supply equipment. The system is controlled from the Operation Control Center (OCC). Centralized control equipment is installed in the OCC and controls the substation and electric room facilities.

The communication method is Ethernet LAN system with TCP/IT, and the components of the system will be structured using general use devices. The optical fiber used in the telecommunication section will be used

To enable easy connection with the P-SCADA system and in order to use general PLC (programmable controller) equipment to save cost, the substation control system should also be based on the IP connection LAN system.



Source : JICA Study Team

Figure 7.48 Standard Substation Connection Diagram

7.9.4 Contact Line System

(1) Feeder

A feeder cable with enough current capacity to supply the required power to trains under the DC 1500V system is selected, as shown in Table 7.43.

The feeder cable to be used will require flexibility for cabling in narrow spaces in some locations.

Sectioning devices in the main line will be installed at such places as the connection point in front of the substations, the branch point to the Depot and the point to the 4th bridge section, which are the necessary points for operation and maintenance work.

(2) Contact Line System

The planned system will be able to keep the necessary voltage for train operation under the DC 1500V system limit, Maximum 1900V and Minimum 1000V based on IEC requirement.

The type of Contact Line is an independent, rigid, two contact line, side friction type, and its structure consists of a T-shaped aluminum supporting material and copper trolley wire with 170mm^2 section. Figure 7.49 shows the standard structure of the line.

The line system will be structured to have a current capacity of 2700A for a 2-hour average maximum, and 6700A for instantaneous maximum based on the estimation of the contact line load.

The T-shaped aluminum support section is 2200mm^2 and the contact wire section is 170mm^2. The sectional calculation gives a total resistance of 0.027Ω as shown in Table 7.43..

Table 7.43 Study of Contact Line Section

PART	Material	Section	Current Capacity	Resistance Ω/km (20°C)	Total Ω/km
Aluminum Trestle	A-6063-T5	2200mm^2	2700A	0.01536	0.0134
Contact Wire	GT-170	170mm^2 (68)60%wear		0.104	

Source: JICA Study Team

The same structure will be applied to both P and N conductors; thus the total resistance for the line is 0.027Ω.

The contact line is supported on the both sides of the track beam by an insulator. The position of the line is adjusted so as to have a set difference to the center to prevent concentrated wearing of the train’s contact plate at some point, such as at a snake-like winding point.

The contact line conductor should have a suitable length for the convenience of construction work, and taking into consideration the material’s change in length due to change in temperature. The middle of the conductor set is equipped with an anchor ring to prevent sliding, and a sliding contact will be used at the connection points.

The section will be installed adjacent to the station area and section trouble may occur from arc transition of the acceleration and re-generation current. Furthermore, section over phenomena may happen from the contact line system accident. As a countermeasure, the use of long middle sections will be considered.

(3) P-side Contact Line Protective Board

A P-side protective board is planned for the areas where the contact line faces the platform, at the turn-out support, and at the places where the height from the ground is not sufficient.

(4) Car Body Earthing Plate

An earthing plate is constructed over the N-side conductor of the track beam taking into account the mechanical strength, bending and other factors and so as not to be an obstacle for earthing the car body.

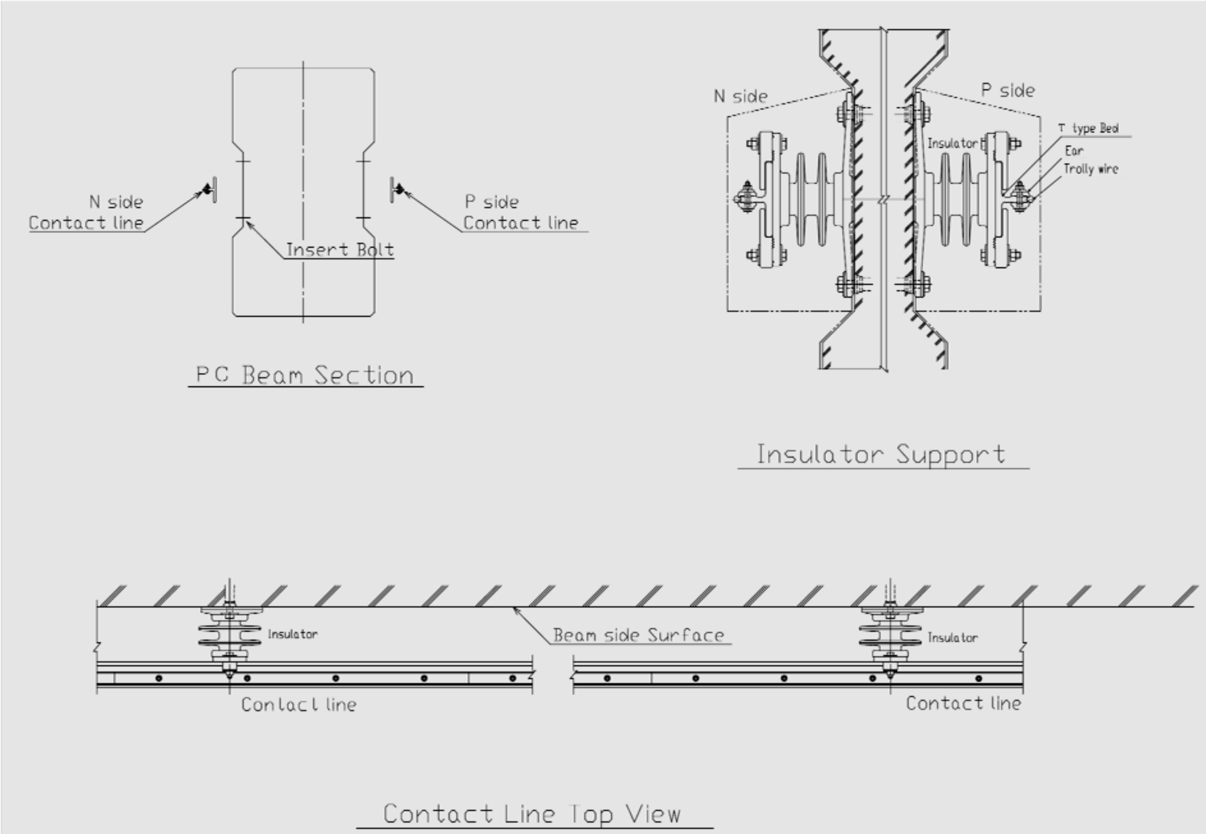
The plate is placed at the platforms of each station and at the location for car maintenance in the Depot.

(5) Lightning Arrester

A lightening arrester is planned to be installed in the contact line system at the draw out point from the substations, the branching point, etc.

Ratings for the arrester is DC 1500V for the P-side conductor and 600V for the N-side conductor. The arrester will be installed in an earthed case on the ground, 2 sets for P and

N contact lines for each bound line totaling 4 sets. The arrester will be installed in the main track contact line system for both P and N with a spacing of 500m.



Source : JICA Study Team

Figure 7.49 Contact Line Structure

7.9.5 Utility Power supply

(1) Power distribution line

Utility power is supplied to each station and the depot with 13.8kV AC from the secondary line's side of the distribution transformers that are installed in the traction substations.

Distribution transformers area placed at both sides and the middle (SS5) of the main line, totaling three distribution transformers. (See Figure 7.46, the lower half of the transmission line system plan.)

As a countermeasure for the utility power stoppage, all the necessary systems have their own back-up supply system such as UPS (unstoppable power source).

An emergency generator requires its own fuel supply and takes much maintenance work to keep it in good condition. Since the starting of an emergency generator takes time, it cannot be used as a countermeasure for momentary power interruptions. In the Project, an emergency generator is planned only for the depot (administrative building).

The power is supplied from both ends and the middle substation structured with a doubled power supply. In case that the ordinary traction substation stops, the electricity power will be supplied by the traction substation of the counter side.

The important utility power supply equipment installed in the station shall be supervised and controlled from the OCC through the P-SCADA system.

Regarding the installation route for the distribution line cable, a cable trench under one side of the track beam will be used.

(2) Utility power supply equipment

In the stations, power needs to be supplied to the station equipment such as escalator, elevator, home door, automatic fare collection equipment, ticket vender, telecommunication and public address equipment, signaling equipment, turn out power source, illumination and air conditioning and other building equipment.

The station power supply is divided into two groups, one for important load and another for ordinary load. The loads that directly affect train operation are handled as important load, which is separated and limited from the ordinary load.

The station and depot load estimation is shown in Table 7.44.

Table 7.44 Loads in each station and depot

STATION NO	STATION NAME	CAPACITY (kVA)	LOAD FACTOR (%)	ACTUAL LOAD (kVA)	Transformer Capacity (kVA)
NO.1	Albrook	500	70	350	4000
NO.2	Balboa	300	70	210	
NO.3	Panama Pacifico	500	70	350	
	Emergency Platform	20	70	14	
NO.4	Loma Coba	300	70	210	
NO.5	Arraijan	300	70	210	4000
Subtotal-1		1920		1344	(1500)
NO.6	Arraijan Mall	500	70	350	
NO.7	Burunga	300	70	210	
NO.8	Nuevo Chorrillo	500	70	350	
NO.9	Caceres	300	70	210	
NO.9-1	Future	300	70	210	
NO.10	Vista Alegre	500	70	350	
NO.11	Vista Alegre2	300	70	210	
NO.12	Nuevo Arraljan	300	70	210	
NO.13	San Berrnadino	300	70	210	
NO.14	Ciudad del Futoro	500	70	350	
	Depot	2500	50	1250	4000
Subtotal-2		6300		3910	(4000)
Total LOAD		8220		5254	12000

Source : JICA Study Team

(3) Cable

For the 15kV line, the XLPE-T 95mm^2 power cable shall be applied.

The voltage drop calculation in the line is shown in Table 7.45, and the calculation is done for the line between the Depot substation and the No 5 station as a worst-case example.

Table 7.45 Voltage Drop in Distribution Line

13.8kV Power Distribution Lines for LPS

Calculation of Voltage Drop

NO.	Electric System: Phase, Nomber of Cables φ	W	Voltage E (V)	Fre-quen-cy f (Hz)	Load: Section	Circuit Capacity P	Unit	Power Factor COSθ	Effi-cien-cy λ	Circuit Current I (A)	Cabling: Type: Circuit Length L (m)	Kind of Cables	Size (mm2)	No. of Cabl H	Current Carrying Capacity Ip (A)	Line Constants: Resistance /km Ra (Ω/km)	Reactance/km Xa (Ω/km)	Impedance: Resistance R=Ra*L *θ/H *1000 (Ω)	Reactance X=Xa*L /H *1000 (Ω)	Voltage drop e (V)	Voltage drop d=e/E *100 (%)	Note
CASE4																						
SS10 to SS5 contrary																						
1	3	3	13800	60	SS-10 ~ Depot	4,155	kVA	0.9	1	193	600	15kV XLPE-1C	95	1	320	0.247	0.143	0.1480	0.0857	57.0	0.41	
2	3	3	13800	60	Depot ~ NO.14 ST	2,905	kVA	0.9	1	135	1,250	15kV XLPE-1C	95	1	320	0.247	0.143	0.3082	0.1785	83.1	0.60	
3	3	3	13800	60	No14 stn ~ NO.13 STA	2,555	kVA	0.9	1	119	1,650	15kV XLPE-1C	95	1	320	0.247	0.143	0.4069	0.2356	96.6	0.70	
4	3	3	13800	60	O13 STA~ NO.12 STA	2,345	kVA	0.9	1	109	850	15kV XLPE-1C	95	1	320	0.247	0.143	0.2096	0.1214	45.6	0.33	
5	3	3	13800	60	lo12 STA~ SS11 STA	2,135	kVA	0.9	1	99	1,300	15kV XLPE-1C	95	1	320	0.247	0.143	0.3206	0.1856	63.3	0.46	
6	3	3	13800	60	lo11STA ~ NO.10 ST	1,925	kVA	0.9	1	89	1,000	15kV XLPE-1C	95	1	320	0.247	0.143	0.2466	0.1428	43.8	0.32	
7	3	3	13800	60	lo10STA ~ NO.9-1 STA	1,575	kVA	0.9	1	73	950	15kV XLPE-1C	95	1	320	0.247	0.143	0.2343	0.1357	34.1	0.25	
8	3	3	13800	60	No9-1stn ~ NO.9 STA	1,365	kVA	0.9	1	63	1,100	15kV XLPE-1C	95	1	320	0.247	0.143	0.2712	0.1571	34.1	0.25	
9	3	3	13800	60	No9 stn ~ NO.8 STA	1,155	kVA	0.9	1	54	1,850	15kV XLPE-1C	95	1	320	0.247	0.143	0.4562	0.2642	49.2	0.36	
10	3	3	13800	60	No8 stn ~ NO.7 STA	805	kVA	0.9	1	37	1,550	15kV XLPE-1C	95	1	320	0.247	0.143	0.3822	0.2213	28.2	0.20	
11	3	3	13800	60	No7 stn ~ NO.6 STA	595	kVA	0.9	1	28	1,000	15kV XLPE-1C	95	1	320	0.247	0.143	0.2466	0.1428	13.8	0.10	
12	3	3	13800	60	No6 Stn ~ NO.5 STA	245	kVA	0.9	1	11	1,200	15kV XLPE-1C	95	1	320	0.247	0.143	0.2959	0.1714	6.5	0.05	
13	3	3	13800	60	No5 Stn ~ SS 6	35	kVA	0.9	1	2	150	15kV XLPE-1C	95	1	320	0.247	0.143	0.0370	0.0214	0.1	0.00	
																			Total	555.5	4.0	

Permissible conducter temperature : 90℃

Ambient tempereture : 40℃

Formura for Voltage Drop : e = K*I*(R*COSθ+X*SINθ)

(K=2: 1φ, K=√3: 3φ)

Source : JICA Study Team

7.9.6 Lightning Protection

(1) Type of Lightning

Lightning is classified as follows based on the area and exposed objects which are influenced by a stroke of lighting.

1) Direct Lightning Stroke

In case of a direct lighting stroke, most of the current by a discharge of lightning travel through human bodies, buildings, equipments, trees, etc. When the light current penetrates the objects and reaches the earth, large scale damage such as breakdown of structure and fire will occur.

2) Induced Lighting

Induced lighting is a high voltage on cables such as power cable, telecommunication cable, antenna, and other metal cables, created by lightning current through electromagnetic induction mechanism when the lightning struck objects such as buildings and trees. A lighting surge, current flow created by transient high voltage due to lighting stroke, sometimes break down equipments such as electric apparatus and telecommunication devices.

3) Backflow Lightning

In case that the ground potential rises when a building is struck by a lightning, a part of the lightning current flows into power cables and telecommunication cables backward from the ground. This phenomenon also causes the lightning surge and the current penetrates electric apparatus and telecommunication devices.

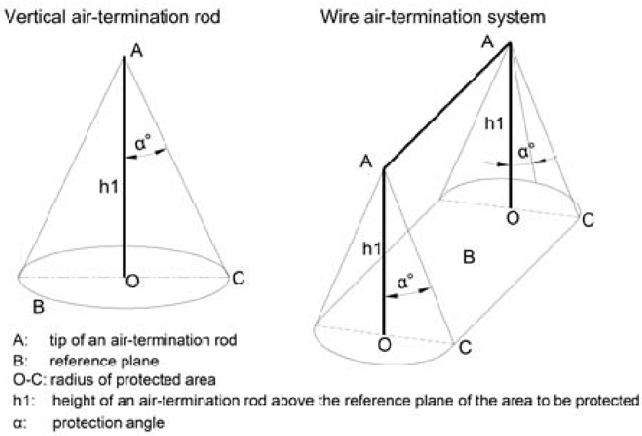
IEC 62305 series and JIS A 4201-2003, the standards of lighting protection, classify the lighting protection system into the external lighting protection system and the internal lighting protection system. The external lighting system, consisting of Air Termination system, Down-conductor system, and Earth Termination system, captures approaching lighting with Air Termination system and discharge the lighting current quickly and efficiently to the ground. The internal lightning protection system is the countermeasures added to the external lighting protection system such as equipotential bonding and safe separate distance in order to reduce the electromagnetic effects of lightning on the object to be protected.

The protection method against direct lightning strokes consists of the external lightning protection system such as surge protective device and internal lightning protection system to protect abnormal over-current in a building. The protection method against induced lightning and backflow lightning is based on the protection measures against lightning surge like surge protective devices, which is an internal lightning protection system, in order to protect equipments in the building. Since lightning exceeding 10kA, which is regarded as the capacity limitation of survey protective device, occurs several times a year in Panama, the external lightning protection system plays an important role.

In this section, the method to install the proper external lightning protection system for monorail girders based on IEC 62305-3 Protection against lightning - Part 3: Physical damage to structures and life hazard and JIS A 4201-2003.

(2) External Lighting Protection System

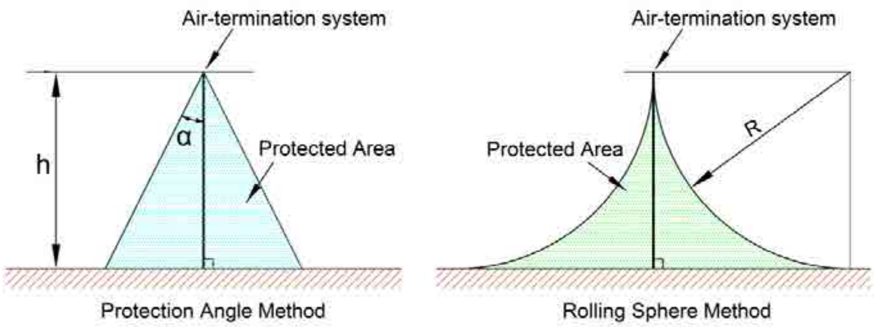
The air-termination system is composed of rods and catenary wires. Meshed conductor is not considered due to its difficulty to be applied to monorail girders.



Source: IEC 62305

Figure 7.50 Air Termination System of External Lightning Protection System

The protected area is calculated by the Protection Angle Method and/or Rolling Sphere Method in accordance with the protection level.



Note: Refer to for h, α, R
Source: JICA Study Team

Figure 7.51 Protection Area

The proper protection level is chosen from four levels - I, II, III, and IV taking into account of the kind and importance of the object to be protected, importance, protection efficiency, cost performance, etc., and the corresponding protection system for the level is applied. According to JIS A 42-1, the lowest level for ordinal buildings should be Level IV while that of dangerous facilities should be Level-II, and the higher levels should be applied in accordance with the condition of the location, the kind and importance of the building.

Table 7.46 Protection Level

Protection Level	Min. lightning current peak value (kA)	Interception Criterion	Protection Angle Method (α)				Rolling Sphere Method R (m)
			h=20	h=30	h=45	h=60	
I	2.9kA	99%	25	*	*	*	20
II	5.4kA	97%	35	25	*	*	30
III	10.1kA	91%	45	35	25	*	45
IV	15.7kA	84%	55	45	35	25	60

Source: IEC 62305

(3) External Lightning Protection System of Monorail (Air-termination system)

The objects to be protected from lightning are monorail's track girders, feeding lines and cables around the girders. Catenary wires (overhead ground wires) will be used for the air-termination systems in the external lightning protection system of the monorail, and the overhead ground wires will be installed above the track girder in such a way that the protection area can cover the girder. For equipping track girders with overhead ground wires, the following three methods are proposed.

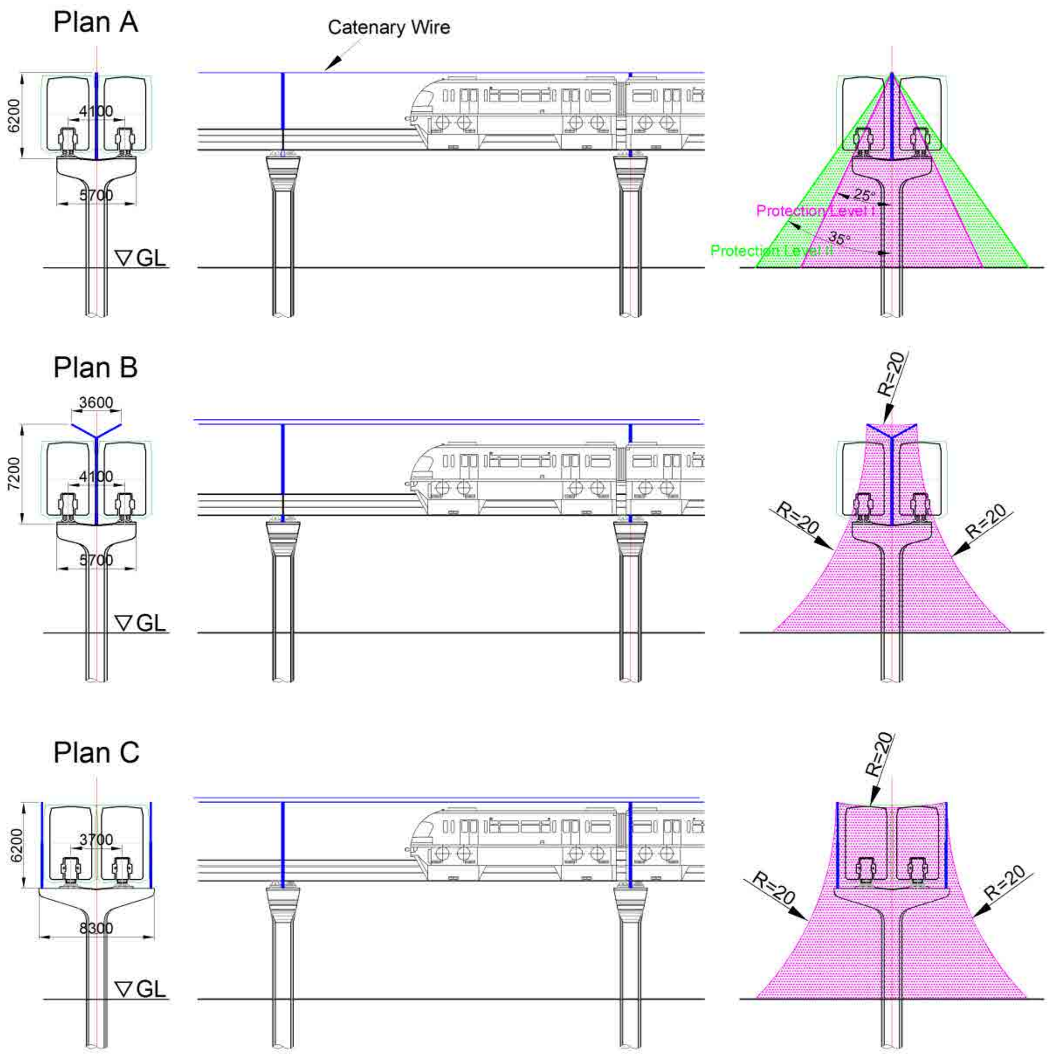
Plan-A: Stretch an overhead ground wire between poles on the pier in the center of track girders

Plan-B: Stretch two overhead ground wire between Y-shape poles on the pier in the center of track girders

Plan-C: Stretch an overhead ground wire between poles on each edge of the pier outside of the track girder

In any plan, the overhead ground wire touches cars if the wire is located at the same level of cars because track girders forms a circular arc in curve sections while overhead wires are stretched between poles like a chord. Therefore, the overhead ground wire will be located at higher position than the roof of the cars.

Among three plans, although Plan-C has advantages for the protection level and protection area, Plan-A was employed in the Project taking into account of cost performance and landscape. Plan-A ensures that the girder, electric lines, and cables are protected at the protection level II. Using rods (lightning rods) with overhead ground wire or applying Plan-B should be considered where higher protection level is required.



Source: JICA Study Team

Figure 7.52 Alternative Plans of Overhead Ground Wire and Protection Area

Table 7.47 Characteristics and Protection Level

	Plan A	Plan B	Plan C
Position of Overhead Ground Wire	top of the pole in the center of track		top of the pole on the both outside of the track
Characteristics	To avoid contact between poles and cars, distance between tracks is 4,100mm which is expanded by 400mm.		To install poles on the both sides, the width of pier head is widened by 3,000m.
	Lightning facilities are the simplest among 3 plans.	Truck structure is smaller than Plan-C	
Protection Level	Level II if overhead ground wire is at the level of the roof of cars	Level I although overhead ground wire is located at a high position	Level I if overhead ground wire is at the level of the roof of cars
Protection Area	In case of Rolling Sphere Method, overhead ground wire should be located at higher position in order to cover protected objected within the protection area.	Protected objects can be covered with the protection area at lower cost than Plan-C.	Cars also included in the protection area. The protection area is the largest of the three.

Source: JICA Study Team

(4) Down-conductor System

A down-conductor system is the connection part between Air-termination System and Earth-termination System in an external lightning protection system. The down-conductor system using reinforcing bars in piers will be employed for the Project. Note that the upper limit of the average space between down conductors is specified for each protection level.

(5) Earth-terminating System

The earth-terminating system using reinforcing bars in foundations for the Project.

7.10 Signaling System

7.10.1 Function of the Signaling System

The signaling system is a safe, punctual and reliable system, which mainly has the following five functions to ensure a safe and efficient train operation.

(1) To control the distance between two trains

The system used for this function is called the Automatic Train Protection system (ATP). There are two ATP types, namely the Fixed Block System and the Moving Block System.

(2) To detect train locations

The system used for this function is called the Train Detection System (TD). There are various types for TD Systems. The track circuit system is generally used for MRT and LRT, which it is not available for monorails. The loop coil system, radio system or axle counter are used for monorails.

(3) To control the turnouts routes in stations and depot

This function is performed by an Interlocking System (IL). When the IL function is achieved with computer, it is called an Electronic Interlocking system or Computer based Interlocking system.

(4) To supervise the operation of trains on the entire line

This function is performed by an Automatic Traffic Supervision system (ATS). In addition to monitoring the condition of train traffic, its functions include making and managing train schedule diagrams, and recovering the train diagram in case of train traffic disturbance. It is carried out by man-machine communication with dispatchers.

(5) To control train operation automatically

An automatic train operation system (ATO) is used to achieve the automatic operation of the trains, which is necessary for one-man operation and driver-less operation.

The signaling system is a core function to ensure safety of train operation. It has a close relationship with train cars. The devices for the signaling systems are classified into on-board type system and ground type system. The signaling system and train cars should be designed together in an integrated manner.

7.10.2 Basic Concept of Signaling System

Table 7.48 shows a summary of the signaling system for the Project. A detailed analysis is described in the following sections.

Table 7.48 Summary of the Basic Concepts of the Project's Signaling System

Item		Basic Concept
Standard	Main Standard	a) IEC 62278: Railway Applications - The specification and demonstration of Reliability, Availability, Maintainability and Safety (RAMS) b) IEEE1474.1, 2,3: Standard for Communication-Based Train Control (CBTC)
	Safety Design	Safety design of SIL4 (Safety Integrity Level 4) is required for: a) ATP b) TD c) IL d) Common components of ATP and ATO
Signal System	ATP	Compared with Fixed block system, Moving block system that is achieved by CBTC (Communication Based Train Control) is recommended.
	TD	As ATP adopts CBTC, TD using CBTC is recommended. Using axle counter is recommended as the secondary TD equipment.
	IL	There is a Collective control system and an Individual control system in IL system configurations. The Individual IL system is located at every station that has a turnout and controls its own turnout, while the Collective IL system is located at main stations and remotely controls the turnouts of other smaller stations. Collective IL system is recommended because it can reduce the number of IL systems.
	ATO	One driver operation with ATO
	ATS	Operation monitoring in OCC and automatic route control according to the train diagram.
Depot System	Stabling yard	Stabling yard: Manual operation by the driver, with a speed limit of 15km/h or less by an on board ATP, also with a wayside signal that is controlled by the Depot interlocking system. CBTC and ATO are not used in the stabling yard.
	Maintenance yard	Manual operation by the driver with wayside signal
Backup System in case of System Failure	CBTC	Fixed block system between stations with wayside signal and axle counters for train detection
	ATS	Manual remote route control by a backup console in OCC
	OCC	Manual point machine (PM) control by IL terminal at stations
	IL	Manual point machine (PM) control by wayside PM control panel or Manual control handle

Source：JICA Study Team

7.10.3 Automatic train protection system (ATP)

(1) Feature of ATP

ATP is related to a train block system to keep a safe distance between the preceding train and following train. In order to avoid a rear-end collision, the ATP automatically controls the train speed.

ATP consists of a ground system and on-board equipment. The on-board system detects the position of its own train, and transmits the information to the ground system. The ground system calculates the LMA (Limit of Moving Authority) and transmits it to the on-board system of the following train. The on-board system calculates the appropriate restricted running pattern of the self-train in accordance with the LMA of the preceding train, the self-train position, and the on-board database. Then the on-board system controls the speed of the self-train according to the calculated restricted running pattern.

Depending on the block portion of the fixed ATP, a conventional system directly transmits the velocity data from the ground system to the on-board system. In the case of modern ATP systems, the ground system sends the LMA of the preceding train to the on-board system, and the on-board system controls the train speed by the speed pattern that is generated in accordance with the speed of the self-train and the LMA. The recent trend is to use the modern ATP system, which has an intelligent on-board system.

(2) Fixed Block and Moving Block

There are fixed block and moving block systems for the implementation of ATP. The fixed block is a traditional system which sets a fixed block section putting only one train in a section. The moving block is a recent system that has no fixed block section, and moves the train up to a safe distance from the preceding train without rear-ending it. The use of the moving block system is recently increasing.

Table 7.49 presents a comparison with the Fixed block system with the Moving block system.

Table 7.49 Comparison of Fixed Block and Moving Block Systems

System	Fixed block system	Moving block system
High density traffic operation	1) In the Fixed block system, minimum train operation interval of 1 min. 50 sec. has been achieved. The block length should be shortened in order to shorten train operation interval time or reduce the running time between stations. 2) To increase the traffic density in the future, additional investments on equipment for new fixed blocks will be necessary.	1) The distance between trains can be shortened to the minimum distance, which enables reduction of travel time between stations and shortens operation intervals. 2) To increase the traffic density in the future, additional equipment are not necessary. 3) It has a high maintenance capability.
Impact at line extension	1) Upon line extension in the future, many more facilities (Track circuit, Transmitter-receiver, etc.) are needed than for the moving block system.	1) Upon future extension of a line, taking CBTC (Communication Based Train Control system) as an example, the position detecting points (transmitter-receiver) will be required much in the same way as they are for the fixed block system, also radio antennas are required according to the extension area. As a track circuit will not be necessary, the moving block system has much less cost than the fixed block system.
Actual applications, Standardization	1) There are many actual applications in MRT/LRT, Monorail and other systems.	1) The moving block system has actual applications in MRT, Monorail system. 2) In new lines, CBTC has become the recent trends. The CBTC standard became the IEEE standard.

Source：JICA Study Team

(3) Selection of ATP Technology

Based on the comparison made in the above table, the moving block system is suitable for the ATP of Panama Metro Line 3. The reasons are as follows.

1) It is suitable for high-density traffic operation. The minimum train operation interval can be reduced to 2 min. or less (e.g. 90 sec.). However, the minimum train operation time interval depends on not only on the ATP performance, but also on the line layout for turn backs at the terminal station. Though many fixed block systems have reduced the minimum train operation time interval to 1 min. 50 sec., the moving block system can more effectively reduce the minimum train operation time interval. This is a great advantage.

2) It is possible to shorten the train operation interval in the future with less facility installation as compared to the fixed block system.

3) The fixed block system is most widely used, however recently the moving block system

has been applied in various systems. The IEEE standard (IEEE1474) for CBTC has also been established. In addition, more and more manufacturers are adapting to the moving block system.

CBTC using the crossed loop was common in early stage (before 2004). In recent years, CBTC with radio is the trend among the moving block systems.

(4) Communication Method between On-board and Ground Systems

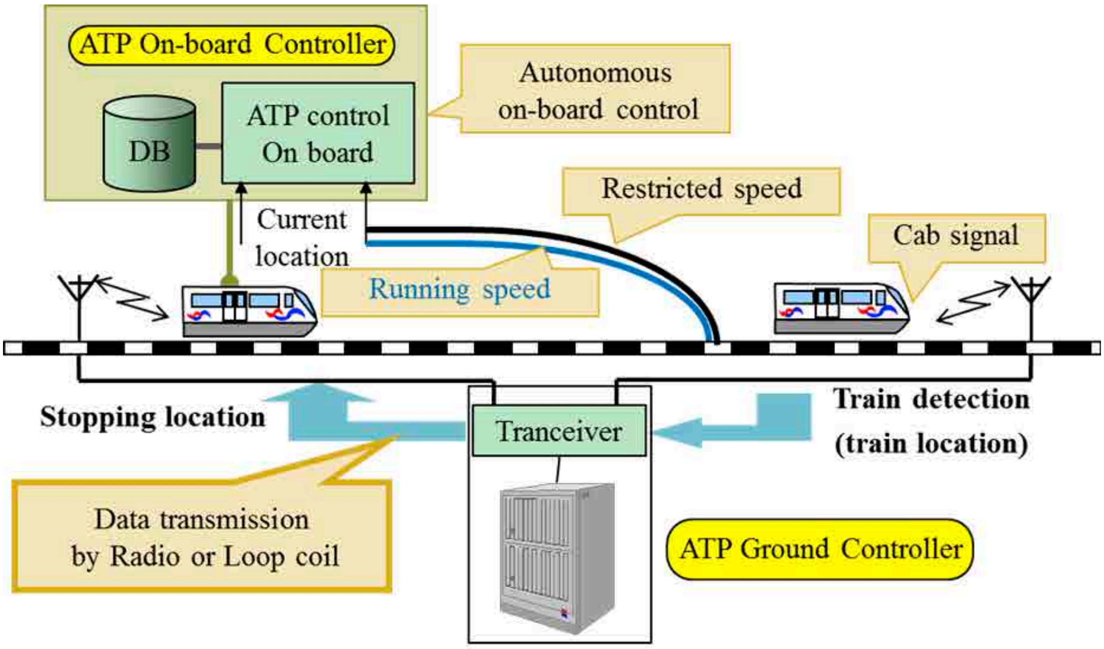
There are the following two methods for communication between the on-board system and the ground system,

a) Loop coil method; Communication between the loop coil antenna on-board and the installed ground loop coil along the beams.

b) Radio system; Communication between the on-board and the ground through a radio antenna. As for the types of antennas, there is the space radio wave antenna and the LCX antenna. In the case of MRT/LRT, the LCX antenna is usually used in the tunnel section, but in the case of Monorail, the space radio wave antenna is used due to the beam structure.

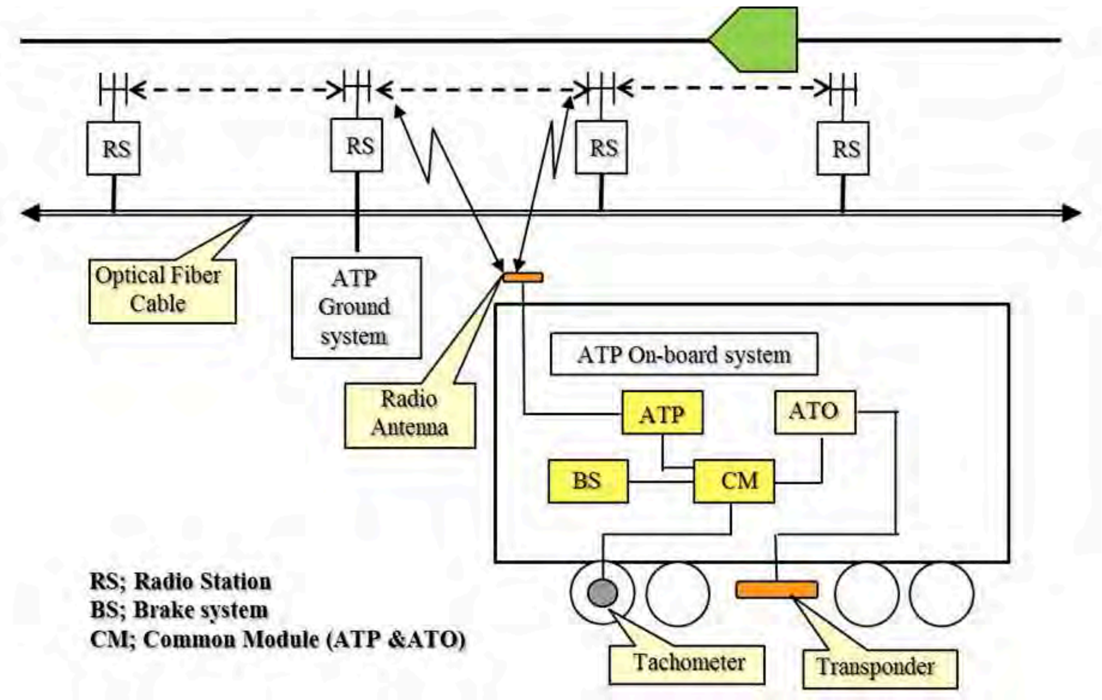
(5) ATP System for Metro Line-3

Figure 7.53 shows the concept of the Automatic Train Protection system (ATP). Figure 7.54 shows the schematic diagram of the ATP system.



Source: JICA Study Team

Figure 7.53 Automatic Train Protection (ATP)



Source：JICA Study Team

Figure 7.54 Schematic Diagram of ATP System

7.10.4 Train Detection system

(1) Methods of Train Detection Systems

There are several methods for train detection. Table 7.50 shows the concept and features of each train detection method.

Table 7.50 Train Detection method

Method	Concept	Features
Track circuit	The system is composed of a transmitter and receiver at both section terminals and left and right rails. When the train enters the section, the train is detected from the short caused by the wheel.	Conventional and proven method. Track circuit is available for MRT and LRT because it is able to put ATP information with modulation technique.
Axle Counter	The system consists of a wheel axle sensor at both sections and the train is detected by counting the check-in and check-out wheel numbers.	Continuous train detection is not possible. Therefore, the train is checked by staff when restarting this system. It is usually used as a secondary TD.
Loop coil	The system consists of a loop coil on the rail and mounted transmitters at the front and rear of a train-set. A train is detected by receiving a transmission to the loop coil from the on-board transmitter.	This is available for rubber tire vehicles such as AGT and monorail.
Train detection method by radio	Train detection is achieved by calculating its location by a tachometer and announcing its location by a radio communication system. The location is adjusted with the transponder on the ground.	This system is used with the Communication Based Train Control system (CBTC). But this has fewer actual applications in use.

Source：JICA Study Team

(2) Train Detection method and ATP type

1) In the case of fixed block system

The track circuit method has been developed for train detection by the shorting of the track circuit by steel wheels in MRT / LRT systems. However the track circuit cannot be used for monorails because of the rubber tires and concrete track.

Therefore train detection by the loop coil method has been adopted in monorails.

2) In the case of moving block system;

In many cases the CBTC is used as the ATP control system. This method detects the train position on board, and transmits it to the ATP ground system by a radio system. In the case of the moving block system (CBTC), the axle counter is used as a backup train detection system.

(3) Train Detection System for Metro Line-3

Train detection information is basic and essential information that is used by all signaling systems. The TD system using CBTC is the preferred system for monorails. By counting the number of revolutions of the wheel from an absolute position given by a transponder (Balise) attached to the beams, the train detection system calculates the train position, and the on-board system sends the train position to the ground system by radio communication.

7.10.5 Interlocking System (IL)

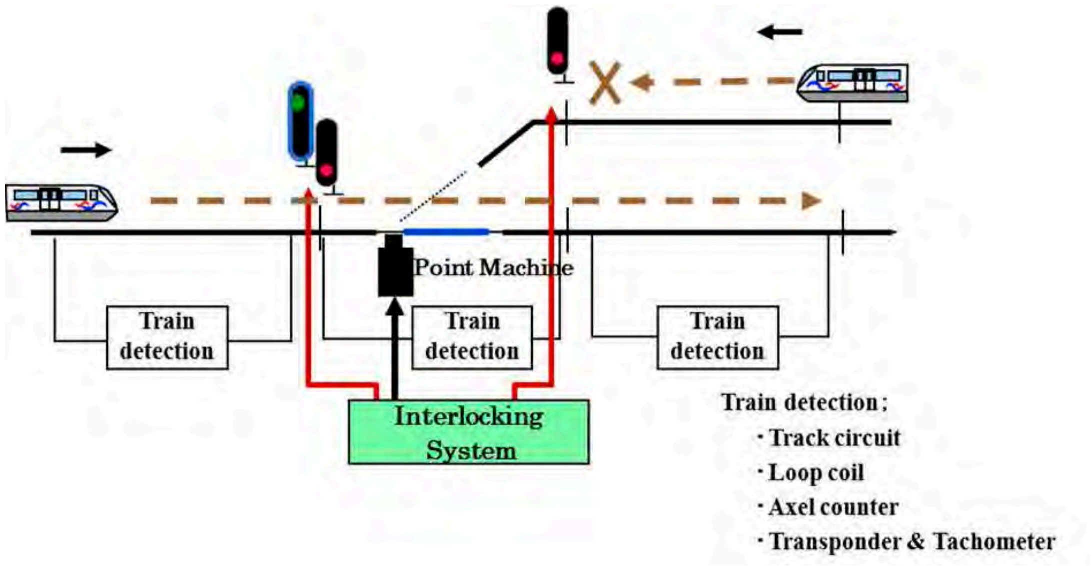
Interlocking means that route setting is executed through an interlocking system that performs interlock between the signals and relevant point machines in the station yard and depot. Interlocking is kept until the train finishes passing through the set route.

There is a collective control system and an individual control system in the configuration of IL systems. The Individual IL system is located in every station that has a turnout, and controls its own turnout. On the other hand, the Collective IL system is located in the main stations, and remotely controls the turnouts of other smaller stations. The Collective IL system can reduce the number of IL systems. The Collective system is recommended for Panama Metro Line-3.

An interlocking system is provided in stations that have branch lines and in the depot. Route setting is executed in conjunction with the signals and the relevant point machines in the depot or station. Furthermore, once a route has been set it is not possible to set another route that would be in conflict with the first.

Normally, a route is set automatically by the Automatic Traffic Supervision system (ATS) installed in the Operations Control Center (OCC). The route can also be set manually by the man-machine function in the OCC. ATS and the interlocking system are connected through a network interface or CTC.

Figure 7.55 shows the concept of the Interlocking system (IL).



Source : JICA Study Team

Figure 7.55 Interlocking System (IL)

7.10.6 Automatic Traffic Supervision System (ATS)

ATS has the following five functions;

1) Diagram Planning

ATS supports train diagram planning including the generation of train run curves from train acceleration, train deceleration and brake performance, distance, curvature and gradient.

2) Diagram Management and Rescheduling

ATS supports the management of train schedule through train tracking and route control results.

3) Train Tracking and Route Control

Automatic Route Setting (ARS) controls the train route automatically at each station.

4) Man-Machine Interface (MMI):

a) MMI functions are as follows:

- Operator (Dispatcher) control with mouse / trackball and graphics display,
- Status information of the devices (Ex. signals, point machines),
- Comparative presentation of planned and actual diagram results),
- Track occupancy information (current situation of train track),
- Route display,
- Route setting function,
- Diagram information display,

b) Console functions: the display console has two functions. One is the monitoring function showing operation status (position of the train, delay time, etc.) and diagram status (plan, actual results, etc.). The other is manual route setting using the input keyboard.

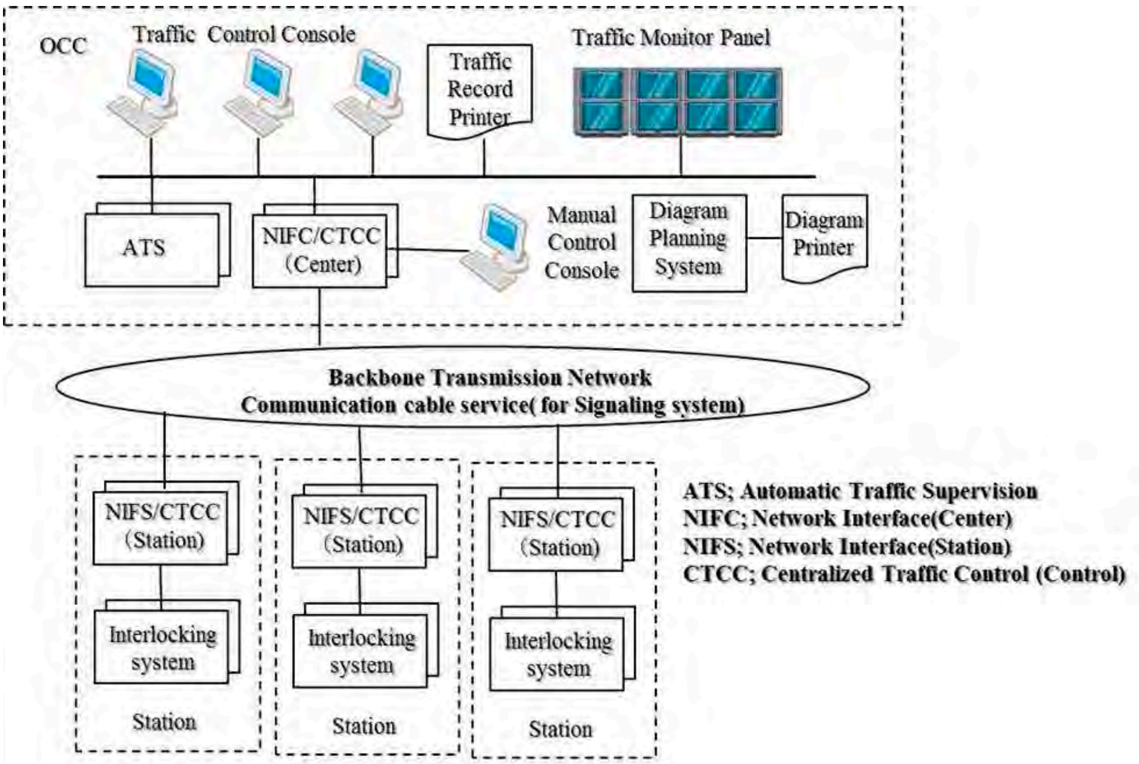
c) Operation display panel; It is located in the OCC. The current status of all train lines and the status of signals and point machines will be displayed on the operation display panel. In this way all the dispatchers and staff can monitor the operation status simultaneously.

5) Centralized Train Control (CTC)

The Centralized Train Control system (CTC) is one of the subsystems of ATS, and has the function of connecting the signaling system of each station and the OCC. The CTC has a transmission function connecting the ATS and IL, and a manual route setting function using the ATS MMI console. These two functions can be configured in the CTC independently, or they can be configured as one of the ATS subsystems.

The CTC consists of a center CTC to be located in the OCC and station CTC's to be located in the stations and Depot. The CTC is connected by an optical fiber cable. All the conditions of the interlocking system are graphically displayed on the monitor of the man-machine interface (MMI).

The CTC or Network interface is employed as the means for connecting ATS and IL. Figure 7.56 shows a schematic diagram of the ATS.



Source：JICA Study Team

Figure 7.56 Schematic Diagram of ATS system

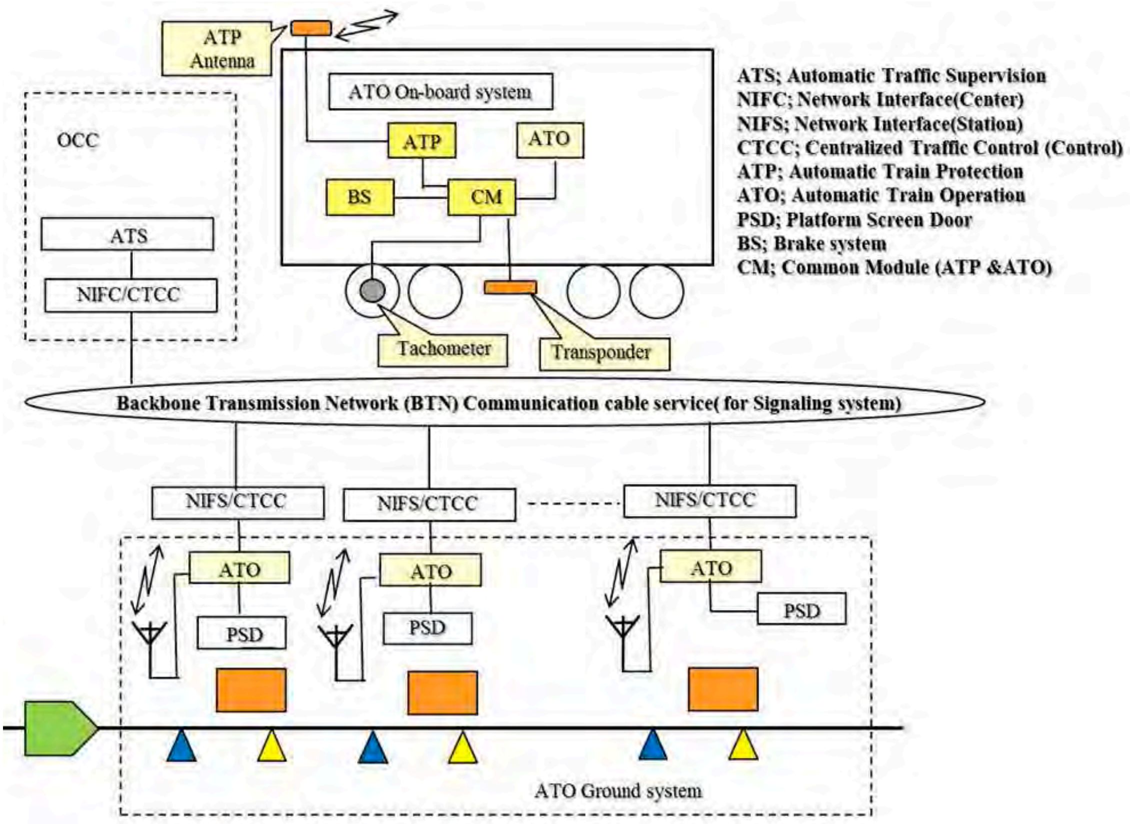
7.10.7 Automatic Train Operation System (ATO)

ATO is introduced to lessen the burden and the required skill of train operators, increase the train density, and ensure a safe, punctual and energy saving operation.

Although ATO enables a driver-less operation, one-driver operation with ATO is recommended for Metro Line-3.

- The safety of train operation should be secured by the ATO system
- The function for punctual operation should be set in the ATO system
- The function to control the position where the trains stop on the platform should be provided by the ATO system.
- The function to prevent the train from starting when passenger safety has not been secured should be provided by the ATO system

The ATO system is composed of the ground system and the on-board system. Figure 7.57 shows the schematic diagram of ATO. For the safety of passengers, platform screen doors (PSD) are provided. PSD is controlled by the ATO.



Source: JICA Study Team

Figure 7.57 Schematic Diagram of ATO system

7.10.8 Signaling system in the Depot

The Depot area includes a stabling yard and a maintenance yard.

1) Stabling yard

Manual operation by driver, supported by on-board ATP with a speed limit of 15km/h. Wayside signals are controlled from the terminal in the Depot SCR, without CBTC and ATO function.

2) Maintenance yard

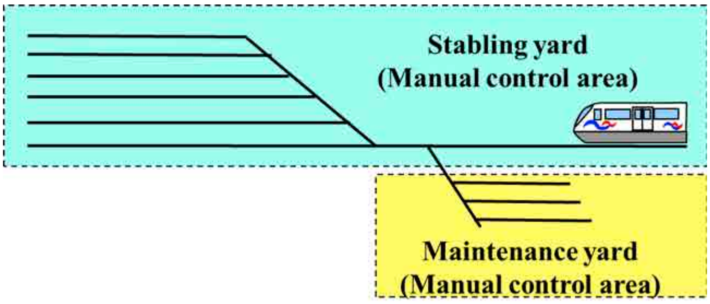
Manual operation with wayside signals which are controlled from the terminal in the Depot SCR.

An axle-counter is used for train detection. Signals and Point machines are controlled by the Depot IL system.

For each storage orbit in the stabling yard, a buffer stopper protection system is provided. For protection purpose, a passive transponder is installed at the limit stop point on each storage orbit. When the train exceeds the limit stop point, the train is stopped by the emergency brake.

The point machine and signaling are controlled by the depot interlocking system. Route control in the depot is performed by the depot dispatcher.

Figure 7.58 shows the Depot control area.



Source：JICA Study Team

Figure 7.58 Depot Control Area

7.10.9 Design Standards for Signaling System

The signaling system is divided into safety-critical systems (vital) and non-vital systems. The SIL4 level safety design is required for the safety-critical parts.

1) Safety-critical (vital) system:
   - ATP (automatic train protection system) ground system, on-board system
   - IL (interlocking system)
   - TD (train detection system)
   - Signal, Point machine
2) Non-Vital System:
   - ATS (automatic traffic supervision system)
   - ATO (Automatic Train Operation System)*
   - MMI (Man-Machine communication for route control and traffic monitoring)

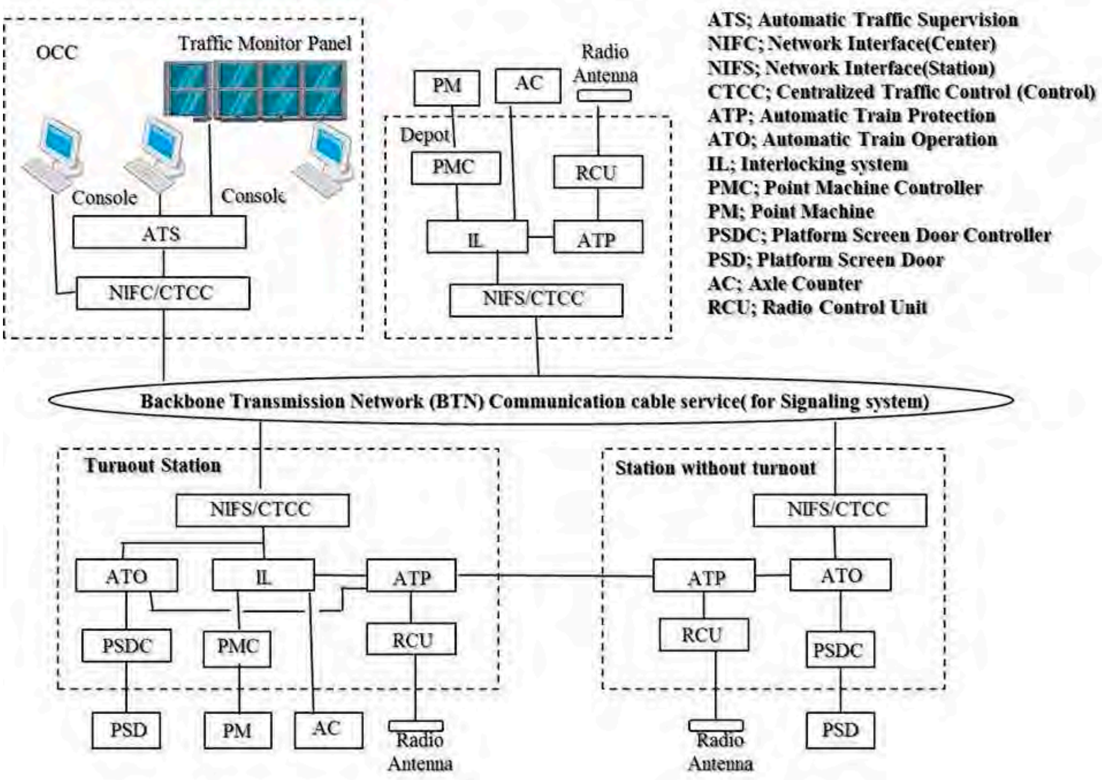
Note; *There is a common component between ATO and ATP, which must be treated as safety critical (Vital) component.

Table 7.51 Design standards for signaling system

System	Design Standards
Train Detection System	• Track circuit for Fixed block system • Loop coil and on board transmitter • TD by CBTC for Moving block system • Safety Level is SL4
Automatic Train Protection System	• ABS for Fixed block system • CBTC for Moving block system • ATP data transmission between ground and on-board is digitalized. • Safety Level is SL4
Interlocking System	• Computer based Interlocking system • System is duplicated • Safety Level is SL4
Automatic Traffic Supervision	• Computer based ATS • Diagram planning Function • Diagram management Function • Automatic Route Setting Function • System is duplicated
Automatic Train Operation	• On-board system is computer based • Transponder is installed at each station for platform screen door control
Depot Signaling System	• Wayside signal • On-board speed limit function • Buffer stopper protection system

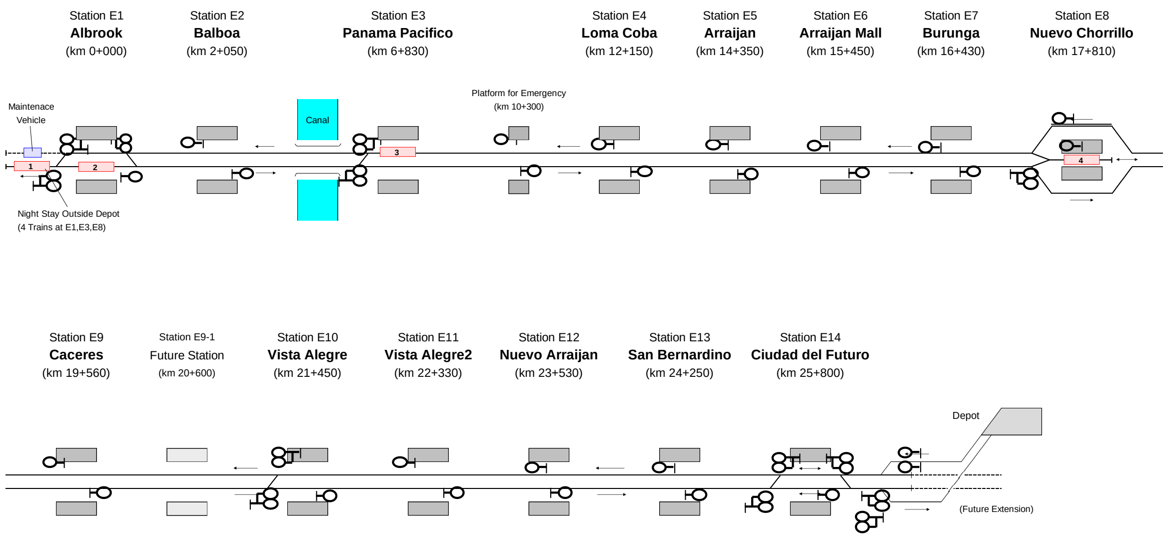
Source：JICA Study Team

Figure 7.59 shows a schematic diagram of the Signaling system. Figure 7.60 shows the Outline of Track layout for Metro Line-3.



Source：JICA Study Team

Figure 7.59 Schematic Diagram of Signaling System



Source：JICA Study Team

Figure 7.60 Outline of Track Layout for Metro Line-3

7.11 Telecommunication

7.11.1 Objectives and required telecommunication service

The objective of a telecommunications system is to assist safe and efficient train operation and support the business environment. To achieve this, the following 3 telecommunication services are required for the project.

(1) Telecommunication system offering voice and data communication services among persons in charge and related sections for the purpose of ensuring safe and smooth train operation.

(2) Telecommunication system offering accurate and valuable information to the passengers in order to increase user service level and support smooth operation.

(3) Telecommunication system offering common network services not only for safety purposes, but also for various sectors of the railway business for the purpose of creating an efficient business environment.

7.11.2 Requirement of telecommunication system

(1) Required function and system

Table 7.52 summarizes the corresponding functions and telecommunication systems for each service type.

Table 7.52 Required Telecommunication Functions and Systems

Required service	Required function	Required system
Telecommunication service for safety	• Dispatching control • Emergency protection	• Radio communication system • Closed Circuit Television (CCTV) system
Telecommunication service for passenger service	• Monitoring of passenger • Information dissemination to the passenger	• Passenger Information System (PIS) that consist of Public Addressing System (PAS) and Passenger Information Display System (PIDS) • Clock System
Administrative and common service	• Communication among related parties • Common network service	• Telephone system • Backbone Transmission Network (BTN)

Source：JICA Study Team

(2) System redundancy

In order to secure redundancy, a core communication system such as the Backbone Transmission Network (BTN) should have redundant functions that ensure continuous system operation when some facilities break down. To keep a system functioning, the doubling of systems (operation and standby) or of facilities (unit redundancy) is generally utilized. The outline of the redundancy of a system is shown in Table 7.53.

Table 7.53 Comparison of redundancy method

Method	Description	Implications
Full duplexed system	• Even if the function of an equipment stops, the function can be performed by another equipment	• Greatest protection against trouble • Highest reliability of these three options • Installation cost is highest of the three options
Half duplexed system	• Only applied to some vital facilities	• Half duplex system is applied when the minimum function should be protected at the time of abnormal condition
Simplex system (Non-redundant system)	• There are no back up systems. Therefore, when equipment function stops, it is impossible to maintain the services	• Unsuitable for an important communication circuit; lowest reliability of the three options

Source：JICA Study Team

Regarding the system security level, the full duplex system is recommended for the dispatching system and trunk communication system.

7.11.3 Network configuration and protocol

(1) Network configuration

The Backbone Transmission Network should be developed in a manner that minimizes network traffic and the influence of system failure. There are three telecommunication network configurations for mass transit systems as shown in Table 7.54.

Table 7.54 Comparison of network configuration

Option	Description	Implications
Ring network	• Systems are connected to a ring network.	• Greatest protection against network trouble, such as severance of network cable or circuit • Highest reliability among these three options.
Star network	• Each system has its own independent network , but all systems are connected to a central system such as an Operation Control Center (OCC)	• Since the number of connecting points is one, the failure of the connection point influences the entire network. • It is easy to expand the network system
Independent network	• Each system has its own independent network .	• Since it is a collection of independent networks, it is not influenced by the failure of other networks.

Source：JICA Study Team

Of these 3 network configurations, the ring network configuration is recommended for each line for the BTN for the following reasons.

a) Widely applied to both railway and communication sector as a backbone network:

Ring network configuration has been standardized by ITU-T G.841.

b) Easy to secure the redundant cable laying:

The 2 cables installed on both sides of the tracks enable communication to be secured even when one of the cables is disconnected.

c) Less number of cable:

Only 4 cable cores are required for the ring network configuration.

d) Traffic distribution advantage:

Network traffic is not concentrated in the center.

(2) Network service by BTN

For railway operation and services, several types of information are required regarding signaling, telecommunication, AFC, power, etc. Each system is installed at the station, wayside, OCC, etc. and uses its own communication protocol.

In order to collect this information according to the requirement of each system, BTN offers the following 2 types of communication network services to the each system as shown in Table 7.55.

Table 7.55 Type of BTN network service

No.	Type of services	Offering BTN facilities	System user
1.	Total communication network service	• OpticalCable • Transmission terminal	CCTV, PA, PIDS, Telephone, etc.
2	Communication Cable service	• Optical Cable	Signaling, Power, AFC, etc.

Source：JICA Study Team

(3) Network protocol by BTN

As mentioned above, Signaling, Power, AFC, etc. have their own network protocol. The BTN transmission terminal with network protocol deals with the telecommunication subsystems including CCTV, PA, PIDS, Telephone system. For this purpose, the following functions are required for the BTN transmission terminal protocol.

a) General and standardized protocol

b) Flexible protocol to meet with several user level protocols

c) Reliable protocol to meet with the ring network configuration

SDH (Synchronous Digital Hierarchy) with STM (Synchronous Transport Module) meets these requirements and is widely utilized by railway and communication sector. This protocol follows the ITU-T standards (G.707. 708, 709, 957, 958). SDH can handle various types of user protocol by being equipped with an interface card.

It is recommended that the SDH be used as the BTN protocol for each line.

(4) User level protocol

Telecommunication sub-systems such as CCTV, PA, PIDS, and telephones have their own user level protocol. It is desirable to utilize common and standardized protocols in order to ensure compatibility of the facilities.

Internet Protocol (IP) is a one of the common and famous protocols for user level. In order to ensure the expandability and compatibility of telecommunication systems with low investment, it is recommended that Internet Protocol (IP) interface be used as much as possible for non-safety computer based equipment, especially for user service level.

7.11.4 Type of telecommunication systems

The telecommunication system for Line-3, which is planned as a monorail, consists of 6 sub-systems:

- Radio communication system.
- Telephone system
- Closed Circuit Television (CCTV) System
- Passenger Information System (PIS)
- Clock System
- Backbone Transmission Network (BTN)

The type of telecommunication system is shown below.

(1) Radio communication system

- Dispatching telephone : between OCC and train
- Emergency communication : from train to OCC
- Train status data : from train to OCC
- Control data : from OCC to train

The system to be used will be called a Digital radio system with a standard antenna or LCX antenna (at Track) and a standard antenna (at Depot). Radio frequency: 400MHz or 800MHz band.

As Metro Line-1 uses 450MHz to 470MHz, it is expected that the same band will be used.

The radio communication user groups are divided into:

a) Train radio communication is exclusively between controllers and train operators in individual mode.

b) Operation communication groups between controllers and railway operation staff in talk group mode.

c) Maintenance radio communication groups between Engineering Controller, maintenance offices and staff in talk group mode.

Mobile radio communication equipment shall be provided for:

a) Train radio in each train cabin.

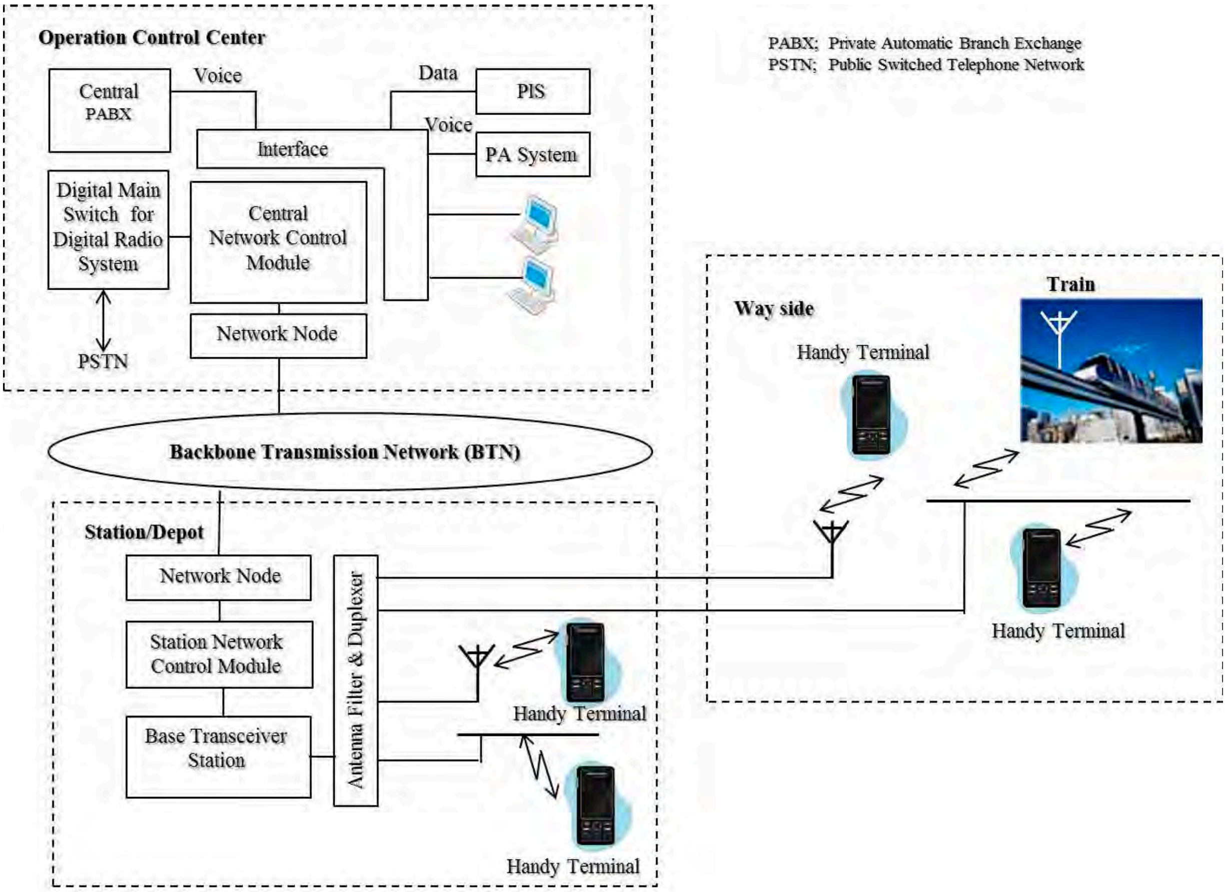
b) Vehicle radio as fixed installed or handheld console type radio.

c) Handheld radio for operation staff like station manager, station personnel, Depot personnel.

d) Handheld radio for maintenance staff like building service, signaling, traction power, communication and other groups.

The Line Controller is able to place announcements in the on-board intercom system in the trains. All controller communications will be recorded on a multi-channel digital voice recorder.

The configuration of the Radio communication system is shown in Figure 7.61



Source：JICA Study Team

Figure 7.61 System Configuration for Digital Radio Communication System

(2) Telephone system

The Telephone system consists of:

- Administrative & general telephone with PABX
- Dispatching telephone
- Operation & Maintenance telephone

For Telephone exchange system the required PABX are as follow:

- PABX with minimum 100 ports is to be provided at all stations.
- PABX with minimum 256 ports is to be provided at terminal stations.
- PABX with minimum 500 ports is to be provided at OCC.

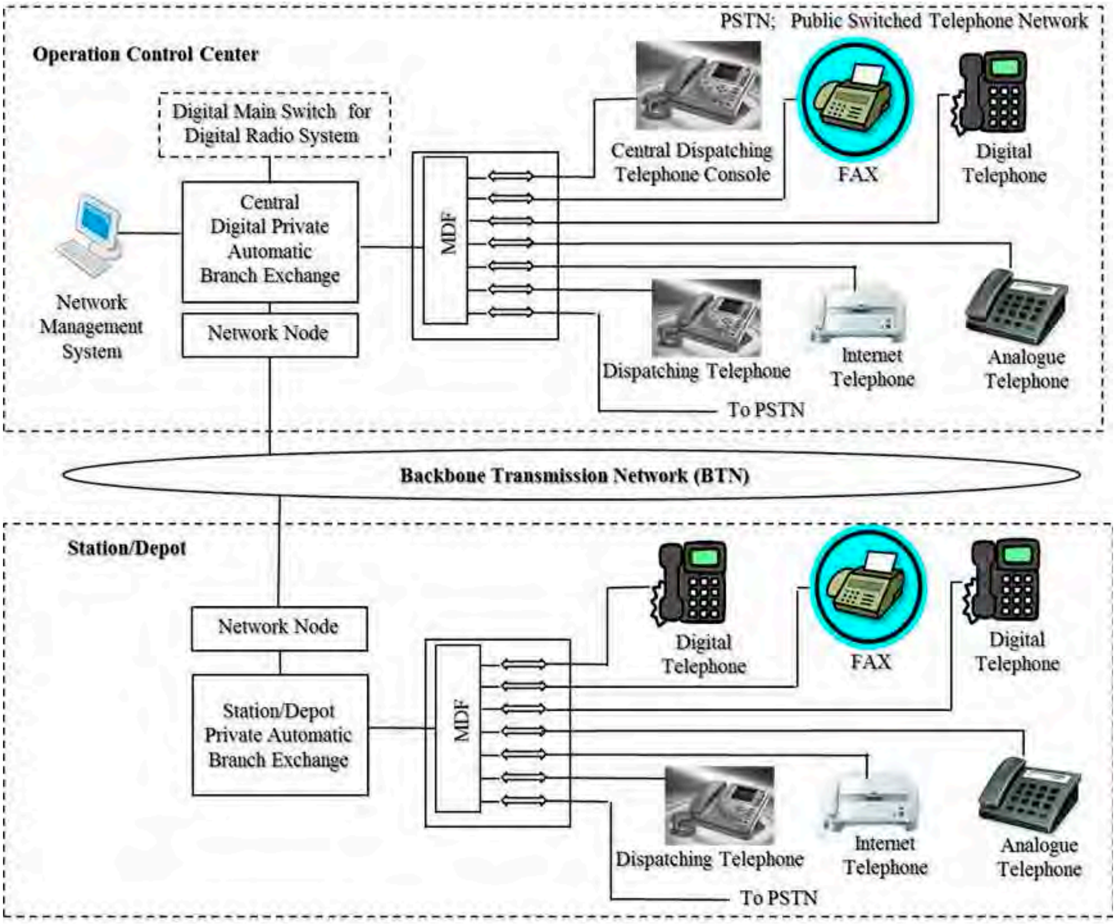
A concentrated telephone system with selective calling function should be adopted. The minimum requirements are as follows:

- Individual calls
- Group calls (Group is preset by the controller)
- Broadcast calls
- Hands-free communication function with speakers, microphone

The digital telephone system for telephone users should have a variable network for telephone communication and should be placed in the following locations:

- Administration offices
- CCR
- Maintenance workshop and offices
- Technical rooms
- Ticketing counters and SCR's
- Designated points in the system (e.g. at platforms)
- Direct line, party line, emergency hot line and other dedicated telephone operations for: Platform to SCR, Chief Supervisor to police and fire brigade, Line Controller to police and fire brigade, Line Controller to SCR's, Engineering Controller to designated maintenance offices (e.g. to Emergency team)

The configuration of the telephone system is shown in Figure 7.62



Source：JICA Study Team

Figure 7.62 System Configuration for Telephone System

(3) Closed Circuit Television (CCTV) system

1) General

The CCTV system not only displays the movements of trains and passengers for the CCR and SCR staff, but it also plays an important role in providing a fast and precise identification of persons. The locations for surveillance will depend on operations and security, but generally include the platforms, passageways, public areas on the concourse, escalator landings, ticket offices, building and technical room entrances. The train operators use their on-board monitors to control passenger movements when boarding and disembarking the train. The Depot Controller monitors the train movements in the Depot areas, the shunting and stabling area, washing plant, workshop track doors and the transition to the main tracks.

The CCTV security system is able to prevent intrusions that would obstruct railway operation. The images taken by cameras are transmitted to the on-board display via wireless local area network to provide a train operator with the entire image of the train. The CCTV security system adopts digital transmission technology. Camera images are digitized at a matrix switch before distribution to the network. The digitization is able to reduce a load of the transmission between stations/depot and OCC.

2) System Description and Function

Fixed cameras for monitoring at the station and OCC level shall be provided. LCD monitors shall be provided for train operators to view door closure. The details of system are as follow:

a) Video Management system

An encoder of the video management system at a station converts camera image into a digital format. The video management system requires password for the purpose of security.

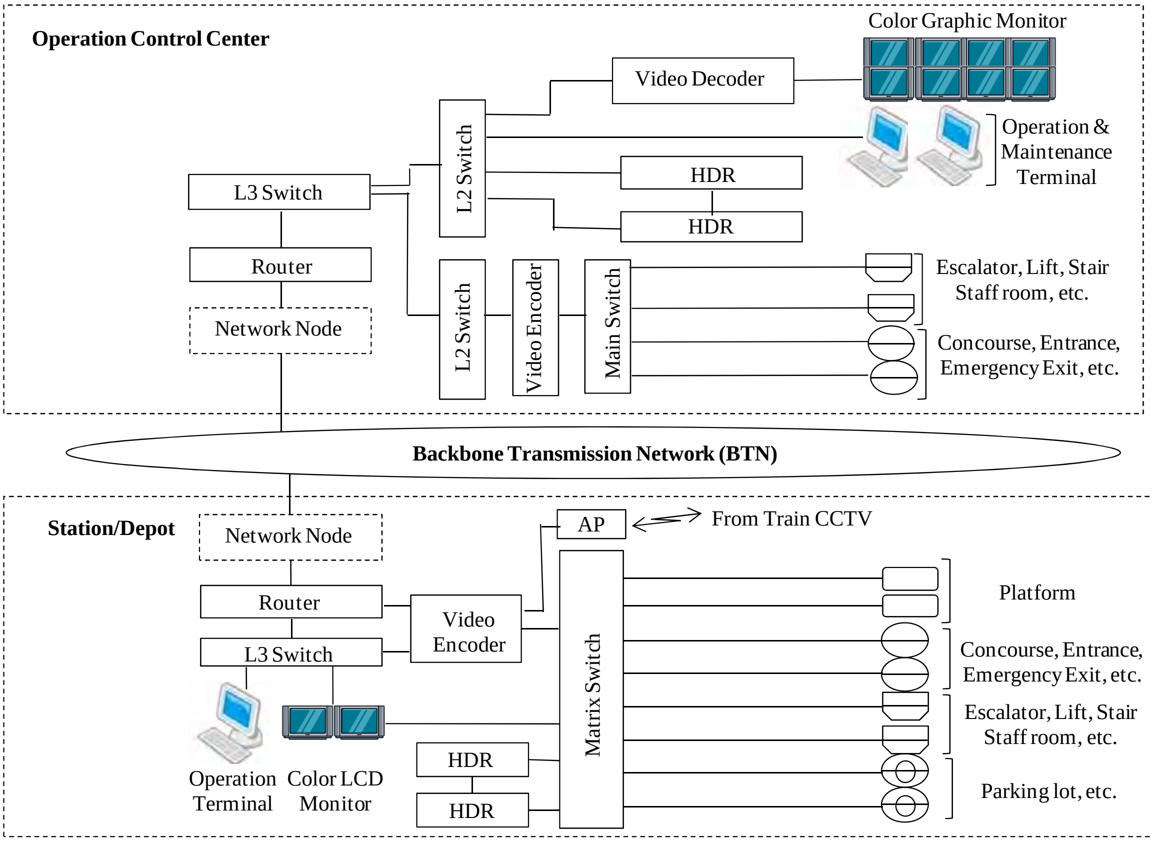
b) Digital Video Recorder

A digital video recorder system is installed at each station and depot in order to record images on the hard disk of the workstation. The recorded images are stored without loss of quality. A few search conditions are selectable according to date, time, camera number and event tag.

c) Entry and exit management (Access control system)

It is necessary to implement entry and exit management by card authentication in important places such as OCC, stations, and Depot. Control is required so that only persons who have obtained permission in advance can enter the area.

The configuration of CCTV is shown in Figure 7.63.



Source : JICA Study Team

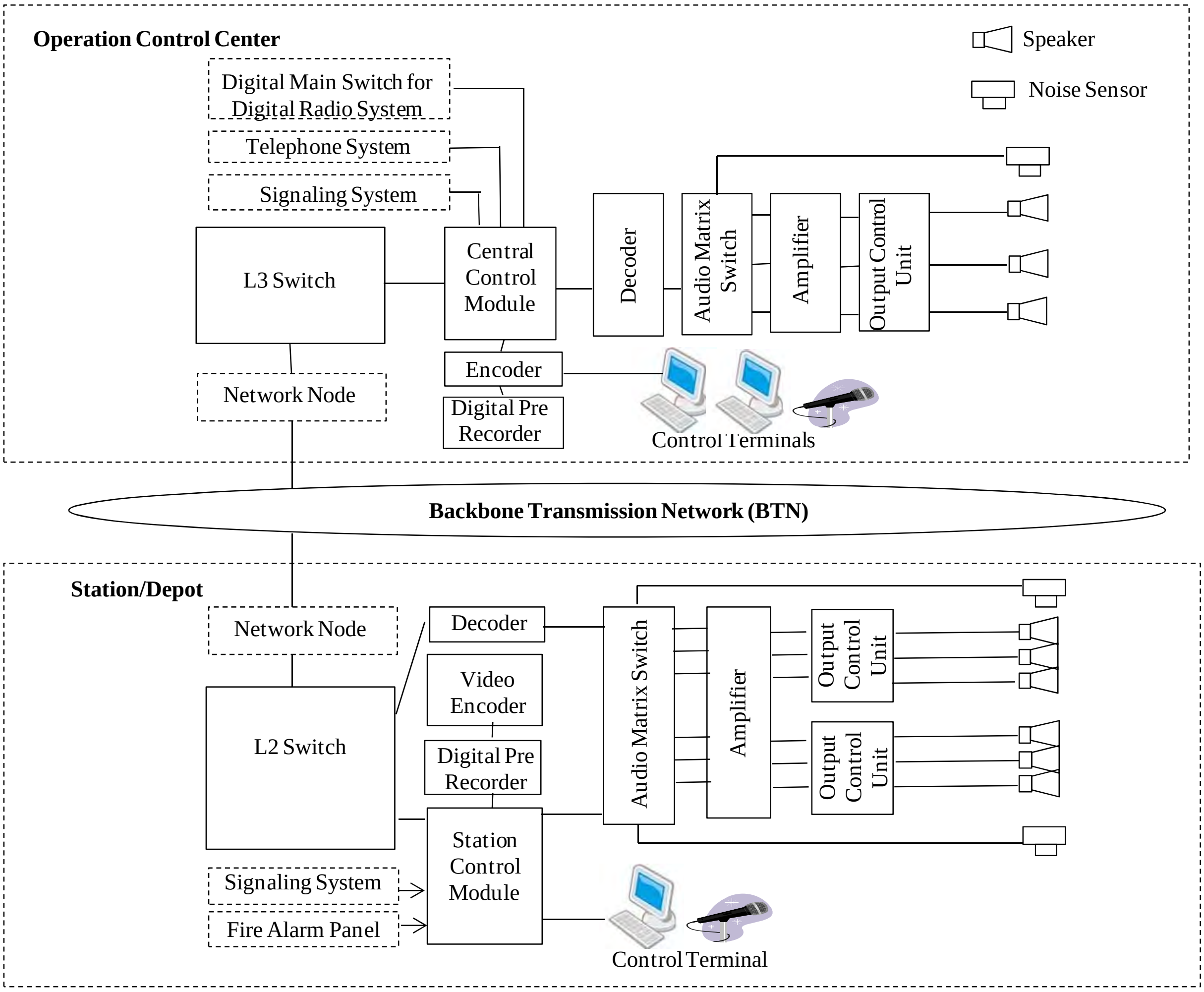
Figure 7.63 System Configuration for Closed Circuit Television (CCTV) System

(4) Public Addressing System (PAS)

1) General

The Public Addressing System broadcasts regular train operation information from controllers and station managers to passengers and also very important announcements to passengers in case of irregularities and emergencies. Besides live announcements, the controllers are able to select pre-recorded announcement from a digital source.

An example of a Public Addressing System (PAS) is shown in Figure 7.64



Source : JICA Study Team

Figure 7.64 System Configuration for Public Address (PA) System

2) System Description and Function

a) OCC- PA system

A workstation and an audio panel are provided for controllers at OCC to broadcast messages to stations.

b) Station PA system

A station public address system provides a workstation and an audio panel for a station controller to broadcast messages only for that station alone. A station is divided into several public address zones and the station controller can select which zone to broadcast the messages and information. The separate public address zones at a station are as follows.

- Platforms,
- Concourse,
- Each elevator,
- Paid – unpaid area,
- Passageways

c) Depot PA system

Similar to the station public address system, the depot area is divided into several zones. The separate zones of the depot area are as follows.

- Maintenance workshop tracks
- Stabling yard tracks
- Auxiliary workshop
- Washing plant

d) Interface to Radio and Telephone system

Interfaces to the radio system and the private automatic branch exchange of the public address system are provided to allow authorized users to make announcements from a selected radio and telephone.

(5) Passenger Information Display System (PIDS)

1) General

Passenger Information Display System (PIDS) is a visual display service to show the incoming train and the outgoing train including the time and special announcements for each station.

The passenger information display system interfaces with the following system.

- Signaling System
- Clock System
- Backbone Transmission Network
- Uninterruptible Power Supply

An example of PIDS is shown in Figure 7.65.

Source：JICA Study Team

Figure 7.65 Example of Passenger Information Display Systems (PIDS)

2) System Description and Function

a) Hardware and Software

The PIDS has the function of providing passengers with information in the form of pre-programmed messages. It is installed in the Central Control Room and is centralized to manage all the displays in the stations. As in the public address system, the pre-programmed messages are displayed in accordance with the Automatic Train Supervision (ATS) of the signaling system.

b) Workstation for Passenger Information Display System

The workstation for passenger information in the OCC has a function that allows for manual operation and monitors automatic operation. The PIDS is designed to create and edit messages with texts, symbols and graphics.

c) OCC Server (Central control module)

The server installed at the OCC has a database for messages which are created or imported from the workstation. A hot-standby server is provided as a redundancy unit.

d) Station Server (Station control module)

A station server can control display units of each station. It is able to distribute messages which are dispatched from OCC to displays.

e) Display Unit

The following display units are provided in the PIDS.

- Concourse Display Unit (2 sets/Concourse)
- Platform Display Unit (2 sets/Platform)

Display units are connected with a control module. It is designed to display an emergency message with high priority.

(6) Master Clock system/Centralized Clock system

1) General

The Master Clock system/Centralized Clock system is designed to provide details of real time and date information. The master clock system is designed to ensure real time accuracy better than +/- 1 second per month and is linked to a GPS System to obtain accurate update information.

2) System Description and Function

a) Overview

The clock system includes, but is not limited to, the following:

- Antenna Unit
- Central Master Clock Unit
- Station/Depot Master Clock Unit
- Fan Out Unit (Distribution)
- Slave Clock Unit

b) Antenna Unit

A GPS receiver at OCC receives the time source via rooftop antenna from GPS satellites. A surge protector is provided against damaging voltages on the antenna coaxial to ground. The antenna unit is able to withstand direct sunlight, wind, rain and other weather condition.

c) Central Master Clock Unit

A central master clock unit receives the time source from the antenna unit and converts it to synchronization pulses. The central master clock unit also distributes the time information to a data transmission system using network transfer protocol. A central master clock unit consists of a GPS receiver which can collect time information and synchronizes the railway system. It has its own oscillator to generate accurate time revised from the GPS time signals. It supports connectivity of Ethernet TCP/IP, RS485 and RS232. It includes network time server to generate NTP (Network Time Protocol) which synchronizes the devices connected to the network. It has a function to be able to deal with power outage and indicates the loss of time synchronization or power.

d) Fan Out Unit (Distribution)

Fan out units are connected to the central clock unit and the station/depot master clock unit for slave clock units.

e) Slave Clock

A slave clock unit is provided in analogue or digital type. Some of the slave clocks are integrated with a passenger information display system. A slave clock is synchronized by the central master clock. The display of the slave clock is clear under any lighting conditions and mounted according to architectural constraints of each location. It is provided in, but not limited to, the following locations indicated in Table 7.56

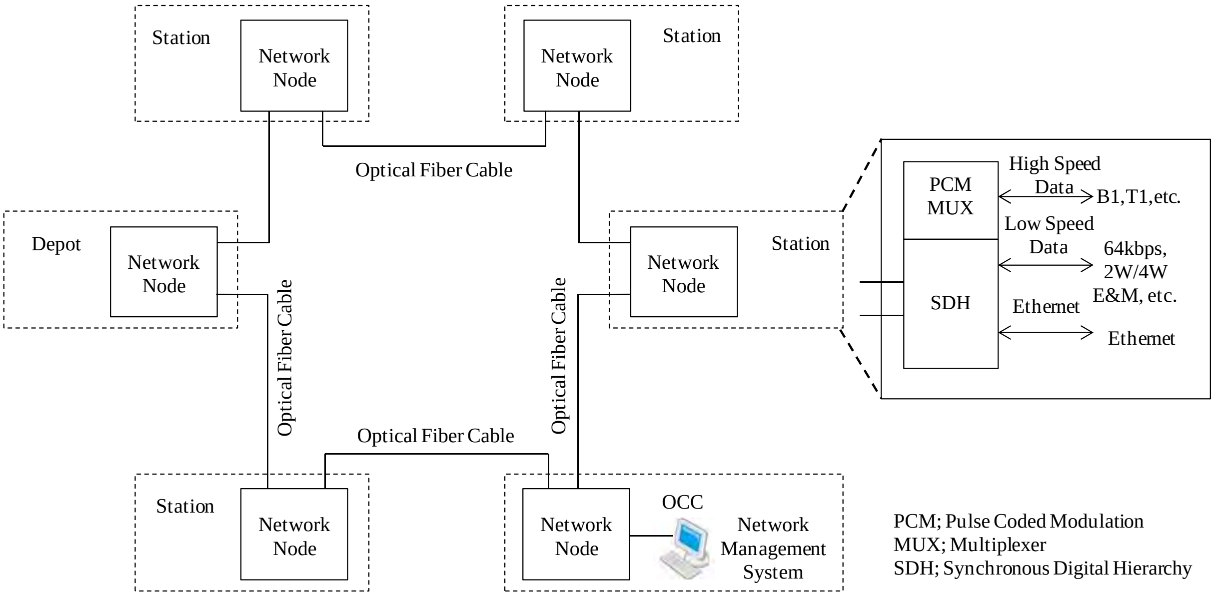
Table 7.56 Outline of Clock locations

Section	Slave clock locations	Position
Administration Building	Central Control Room (CCR) Entrance Area Social Room	On the walls On the ceilings On the walls
Depot	In the workshop (on track) Selected Office Stabling Area	On walls or pillars In trackside sight In trackside sight
Station	Station Control Room(SCR) Platform Area Concourse Area	On the walls In passengers sight (PIS) In passengers sight (PIS)

Source : JICA Study Team

(7) Backbone Transmission Network (BTN)

The Backbone Transmission Network (BTN) shall be the communications backbone between the OCC, stations, power stations and the depot.



Source : JICA Study Team

Figure 7.66 System Configuration for Backbone Transmission Network (BTN) System

The configuration of the Backbone Transmission Network (BTN) is shown in Figure 7.66.

As mentioned above, the radio communication system is indispensable for securing safe and efficient train operation. For the selection of the radio communication system, several matters should be considered, such as the interval of the base transceiver station, level of external noise, and the characteristics of radio wave propagation. The following Table 7.57 makes a general comparison of radio communication systems.

Table 7.57 General comparison of radio systems

Item	Inductive Radio (IR)	Space Wave Radio (SR)	Leakage Coaxial Cable (LCX)
Method	Electromagnetic induction	Radio Wave	Radio Wave
Frequency	LF Band (30kHz-300kHz)	UHF/VHF band (150MHz, 400MHz, 800MHz band)	UHF/VHF band (150MHz, 400MHz, 800MHz band)
General applicable location	Underground	Open space	Underground or Open space
Interval of Base Transceiver Station	Approx. 1km	Approx. 2km	Approx. 2km
Digitalization	Difficult	Easy	Easy
Transmission speed	Low	High	High
External noise strength	Weak	Weak	Strong
Applicability for urban new transport system	Low	High	High

Source：JICA Study Team

7.11.5 Design standards and function

The design standards, functions and performance to be adopted for telecommunication systems are shown in Table 7.58.

Table 7.58 Design standards

System	Design Standards
Train radio communication	Digital radio system with standard antenna or LCX antenna (at Track) and standard antenna (at Depot). Radio frequency: 400MHz or 800MHz band. The radio communication system shall bear both Voice and data.
Telephone exchange	PABX with minimum 100 ports is to be provided at all stations, an exchange with minimum 256 ports to be provided at terminal stations. Minimum 500 port exchange at OCC.
Dispatching Telephone System	Concentrated telephone system with selective calling function should be adopted. Minimum requirements are as follows: • Individual calls. • Group calls • Broadcast calls. • Hands free communication function via speakers and microphones.
Closed Circuit Television System	Fixed and PTZ type cameras shall be provided with station and OCC level monitoring capability. LCD monitors shall be provided for operators to view door closure.
Clock System	Centralized Clock system should be used. Accurate display of time through a synchronization system of slave clocks driven by a master clock at the OCC and sub–master clock in station/depots. This shall also be used for the synchronization of other systems.
Public Addressing System	Public Addressing System covering all platform and concourse areas with local as well as central announcement capability.
Passenger Information Display System	LED/LCD based boards with adequate visibility to be installed at convenient locations in all stations to provide visual indication of the status of the running trains, and also special messages in case of emergencies.
Backbone Transmission Network System	SDH or Gbps/Mbps Ethernet.
Interface	Common and international interface shall be applied as much as possible.
System redundancy (Major system)	Full duplex system for both Mobile Radio base and master station equipment. Path Redundancy provided for Optical Fiber Cable in ring configuration.

Source：JICA Study Team

Chapter 8 Project Implementation Plan

8.1 Engineering Service

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

8.1.1 Engineering Services prior to Construction

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

8.1.2 Engineering Services during Construction

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

8.1.3 Engineering Services after Construction

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

8.2 Land Acquisition

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

Table 8.1 Land Acquisition Summary

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

Source: JICA Study Team

8.3 Project Cost Estimate

8.3.1 Cost Estimate Conditions

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

Table 8.2 Cost estimate conditions

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

Source: JICA Study Team

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

8.3.2 Construction Cost Breakdown

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

8.3.3 Consultant Fees

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

Table 8.3 Consultant fees

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

Source: JICA Study Team

8.3.4 Cost Estimate Results

(1) Initial investment costs

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

Table 8.4 Construction costs

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

Note: Interest during construction is calculated based on the assumption that the loan amount by Japanese ODA loan for 70% of the total cost, while the rest is financed as equity.
Source: JICA Study Team

(2) Additional investment costs

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

Table 8.5 Additional investment costs

Base year for cost estimation: October, 2013
Exchange rate: USD 1.00 = JPY 99.7

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

Note: All prices are as of October, 2013, and do not include price escalation.
Source: JICA Study Team

8.3.5 Comparison with the METI Study

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

Table 8.6 Comparison of project Cost Estimates

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

Source: JICA Study Team

8.4 Construction Plan

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

To ensure fairness of procurement process as well as project implementation,
information should not be disclosed for a fixed period.

Source: JICA Study Team

Figure 8.1 Construction sequence in Panamericana road widening section

8.4.1 Substructure

The substructure of a monorail is the same as the supporting structure for a general structure and no special forms or construction methods are required. Cast-in-place piles, which have low vibration and noise, are used for the foundation. Traffic management appropriate for each construction site will be implemented as construction equipment will occupy an approximate area of 8.0m width during construction. Construction procedures for piles and piers are shown in the table below.

Table 8.7 Pile and pier construction procedures

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

Source: JICA Study Team

8.4.2 Superstructure

(1) PC beam fabrication

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

(2) PC beam erection

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

Source: JICA Study Team

Figure 8.2 PC beam erection

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

(3) PC beam erection on the 4th Panama Canal Bridge

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

Source: JICA Study Team

Figure 8.3 Beam transport by cranes and by beam transport and erection machine

(4) Installation of beams in the depot

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

(5) Other civil construction works

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

8.4.3 Installation of Electric Power, Signal and Communications Systems

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

Source: JICA Study Team

Figure 8.4 Maintenance vehicle

8.4.4 Traffic Management Plans and Safety Management Plans during Construction

(1) Traffic management plan

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

Table 8.8 Procedure for establishing the Traffic Management Plan

To ensure fairness of procurement process as well as project implementation,
information should not be disclosed for a fixed period.

Source: JICA Study Team

(2) Safety management plan

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

8.4.5 Procurement of Materials and Equipment

(1) Construction materials and equipment

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

Table 8.9 Procurement of materials and equipment

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

Source: JICA Study Team

(2) Construction machinery

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

(3) Civil construction labor

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

8.4.6 Consulting Services

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

Table 8.10 Consulting services

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

Source: JICA Study Team

8.4.7 Construction Schedule

(1) Preconditions

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

(2) Related construction

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

Table 8.11 Proposed process for civil works

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

Source: JICA Study Team

(3) Construction Schedule

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

Table 8.12 Preparation stage preconditions

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

Source: JICA Study Team

Table 8.13 Construction stage preconditions

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

Source: JICA Study Team

Table 8.14 Construction schedule

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

Source: JICA Study Team

8.5 Procurement Package

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

8.5.1 Constract for Construction

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

8.5.2 Contract for Design - Build

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

8.5.3 EPC/Turnkey

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

8.5.4 Procurement Package for Line-3

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

8.6 Public-Private Partnership

Both the Panamanian and Japanese sides, public or private, have not expressed an intention to implement the proposed project under a public-private partnership (PPP) scheme. As discussed in detail in Chapter 9, the on-going Line-1 project is implemented as a public investment project, and so is the proposed setup for the Line-3 project. However, taking into account the recent experience in the sector in Latin America and other region as well as the massive investment requirement and new technical and operational challenges faced by the project, the applicability of PPP to the project, as an alternative to the public implementation, is analyzed in this section on a preliminary basis.

8.6.1 Environment for PPPs in Panama

(1) Regulatory and Institutional Framework

Private participation in infrastructure projects has not been regulated by PPP-specific legislation in Panama. A new comprehensive PPP law (Bill 349 of 2011) was sent to the National Assembly in late 2011, but it was withdrawn due to the strong opposition from public-sector workers. PPPs have been implemented based on generally applicable laws and project-specific laws, regulations and/or contract laws, rather than PPP-specific legislation. Hence the regulatory and institutional framework that has been applied varies sector by sector.

However, most recently, as explained in Section 8.6.3 below, it is understood that Law 5 of 1988 as amended in 2010, or the Administrative Concession Law, may serve as the legal basis for new concessions of public infrastructure projects in general, according to the Ministry of Economy and Finance (MEF).

(2) PPP Experience by Sector

Although the regulatory and institutional frameworks have been fragmented, PPP opportunities exist among various infrastructure sectors in Panama. The recent developments are summarized as follows.[1]

1) Urban Public Transport[2]

The new urban bus transportation service was originally planned through technical assistance of Public-Private Initiative Advisory Facility (PPIAF) in 2007. The Land Transport and Transit Authority (ATTT, "Autoridad del Tránsito y Transporte Terrestre") invited bids for the operation of a public bus transportation system in the metropolitan area of Panama. Two national and four foreign companies applied to participate in the bidding process and the concession was granted to "Transporte Masivo de Panamá, S.A." in 2010. The concessionaire has invested over US$ 300 million in the project including 1,200 new vehicles. In July 2010, ATTT carried out the tender for the financial administration of the Metro Bus card system and the Metro Bus card usage was launched in 2012 by the concessionaire, Sonda.

2) Railways

Panama Canal Railway is operated under a concession contract determined under the Contract Law 15 of 1998. See Chapter 8 for details.

3) Roads

Law 5 of 1988 regulates concession projects for roads and airports. Significant toll road projects such as the Northern Corridor (Corredor Norte) and Southern Corridor (Corredor

1 The information in the present section is mainly taken from "Evaluating the Environment for Public-Private Partnerships in Latin America and the Caribbean" (2010 and 2013) by Economist Intelligence Unit.

2 Information on the urban bus transport section is taken from "PPIAF Assistance in Panama" (PPIAF, July 2012).

Sur) in Panama City were developed under this framework. However, after an international audit projected serious revenue shortfalls due to poor revenue forecasting of the concessions, the government decided to bail out the concessionaires (PYCSA and ICA) to make urgent investments such as the widening of the roads. The government established the National Highway Company (ENA, "Empresa Nacional de Autopistas") by Law 76 of 2010 and undertook the concessions. ENA financed the bailout fund by issuing bonds using its future toll revenues as collateral. Its debt is off the national government's balance sheet.

4) Water

Projects in the water sector have also faced challenges. When Law 2 of 1997 established the legal framework to incorporate private sector capital in the sector, the public water company IDAAN, National Water and Sewer Institute ("Instituto de Acueductos y Alcantarillados Nacionales"), was included in the privatization process. However, the process was suspended following violent demonstrations in Panama City. The National Assembly passed Law 77 of 2001 granting the organization more financial autonomy. The government also allowed the private sector to take charge of limited services such as metering and billing.

5) Other Sectors

The electricity industry was reformed in the mid-1990s and the former state-owned power company was unbundled into generation, transmission and distribution. The distribution companies were privatized and private sector investment in generation was incorporated in the sector. However, there is persistent political pressure to involve the state in generation to keep electricity prices lower.

Seaport PPPs have been covered through contract laws approved by the National Assembly with a separate judicial arrangement for each port on an ad hoc basis. For example, the operation and administration of the Ports of Balboa and Cristóbal were granted to Panama Ports Company under a 25-year concession in 1997; the contract was approved through a specific law (Law 5 of 1997) by the National Assembly.

For industrial and commercial property development, the Panama Pacífico Special Economic Zone was created in a former U.S. Air base site in west of the Panama Canal on the Pacific coast. Based on the law passed in 2004, a 40-year concession was tendered in 2007 and awarded to an international property developer (London & Regional Properties). There is a revenue share mechanism involved in the concession and the government will take capital gain share from the granted land.

(3) Investment Climate

Panama is known to have an investor-friendly economy. There are few restrictions on foreign investment. Because of its dollarized economy, there are no restrictions on payments abroad or repatriation of capital by foreign investors; and both local and foreign investors can maintain foreign currency accounts locally or abroad. Law 54 of 1998 stipulates the Legal Stability Regime, in which investors who meet certain requirements can benefit from receiving a government guarantee pursuant to which any future legislation that may be less favorable than the existing laws shall not apply to the project registered to the government. Also, various other investment incentives are offered to investors in specific sectors such as the Petroleum Free Zone and Colon Free Zone. For the Line-1 project, the contractors are given tax exemption by Law 62 of 2010.

8.6.2 Applicability of PPP to the Project

(1) SMP's Transformation into Metro de Panamá, S.A.

In November 2013, Law 109 of 2013 was enacted for the establishment of regulatory framework of Metro transportation system and the creation of a 100% state-owned company named Metro de Panamá, S.A., which will take over the entire organization, functions and operation of the existing SMP. This new corporation is considered as the executing agency of the ODA loan project in implementation stage and, if it is the case, the granting entity on behalf of the government for the concession that involves the private sector participation.

However, according to the legal opinion provided by the SMP officials[3], the extent of financial independence of the company is quite limited as summarized as follows:

The new company will belong to the non-financial state-owned enterprise sector, which means the company is under umbrella of the national fiscal system. Just like many other government agencies, it will fully rely on the national budget appropriation since it is anticipated that the Metro projects are financially not viable and require massive amount of government subsidy for its capital and operational expenditure.

Although the said law allows the company to directly borrow domestic and external loans with or without sovereign guarantee, the funding structure applied to Metro Line-3 under ODA loan is considered to be similar to that of Line-1; where the government will be the borrower of donor loans. On-lending arrangement from the government to the company is not planned and the loan proceeds will be recognized as the government contribution or subsidy to the company.

The law allows the company to implement concessions of Metro systems as discussed below in detail. However, it will depend on the scheme that the State benefits the most and is subject to the government approval.

(2) Law 5 of 1988 as amended: Administrative Concession Law

Despite the withdrawal of the new comprehensive PPP legislation by the current administration in 2011, according to MEF officials[4], Law 5 of 1988 and its amendments by Law 76 of 2010, etc., or the Administrative Concession Law, virtually serves as the legal basis for new public infrastructure projects with private sector participation. This is also reconfirmed for the Metro projects lately, by Law 109 of 2013 on the regulatory framework of Metro transportation system, which stipulates that the corporation shall follow the Administrative Concession Law for its concession projects.

The concession of public works, as provided by Law 5 of 2013, gives a private sector concessionaire the long-term right to use all utility assets conferred to the concessionaire, including the responsibility for all operation and investment. Salient features of the law are summarized as follows:

1) Applicable Projects (Articles 1 and 3)

The law establishes the administrative concession system for the execution of public works applicable to the construction, improvement, maintenance, conservation,

[3] The legal opinion provided by SMP officials on January 27, 2014 upon the inquiry by JICA Study Team on financial management of the new state-owned company.

[4] Interview by the JICA Study Team with the officials of the Directorate of Public Policies, MEF held on October 24, 2013.

restoration and development of roads, highways and other works that the Cabinet qualifies as public interest. The law defines the public interest as "an improvement of permanent nature and for the public use that would be built on the nation's property, or expropriated or acquired by the nation, and that at the end of the concession would be returned to the nation free of costs, encumbrances or claims and in good condition of use and repair that would guarantee a useful life and maintenance costs that satisfy the granting entity."

2) Risk Allocation and Government Support (Article 2)

The concession agreement shall establish the precise allocation of risk between the state and the concessionaire, which may include the risks of construction, operation and maintenance, availability of public services, demand, environmental issues, changes in legislation and events of force majeure. For the benefit of the users and financial viability of the concession, the government may take supporting measures for the project such as availability payments, contributions to reduce effective tariff for the users, etc.

3) Concessionaire (Articles 4 and 5)

Concessionaires may be legal entities or joint ventures of the public and private sectors. Consortiums formed by a group of private entities may be allowed depending on the granting entity's consideration. A consortium must be formed by Panamanian companies and, in case there is a foreign member, it must be represented by a Panamanian participant.

4) Project Preparation and Tender Process (Articles 6, 10 and 11)

Before its implementation, the project for concession must be approved by the Cabinet upon a proposal submitted by the granting entity (the implementing government agency). With its proposal to the Cabinet, the soliciting agency presents the technical study of the project prepared by an independent company. The law also stipulates the selection process for the concessionaire, which includes prequalification and bidding. There are no specific bidding parameters determined by the law, which stipulates that the concession shall be awarded to the bidder with the best proposal in the technical and financial conditions. The granted concession must be approved by the Cabinet.

5) Concession Agreement (Article 12)

The concession agreement must include: (i) name, nationality and domicile of the concessionaire; (ii) object under concession; (iii) concession period; (iv) the concessionaire's investment amount; (v) demarcation of the object area; (vi) general and special conditions, and rights and obligations; (vii) the characteristics and general plan of the works; (viii) the period of the physical works; (ix) the guarantees and financing that the concessionaire should provide; (x) tariff and tariff revision system, which should be approved by the Cabinet; (xi) conditions for administrative repossession of the concession by the State; (xii) causes for termination of the concession; (xiii) the expressed submission of the concessionaire to the legal regimen established in this law; and (xiv) the time period and the total recoverable amount which shall include the investment and a reasonable profit duly agreed upon. It is noted that the tariff and its revision are subject to approval by the Cabinet.

6) Obligations of Concessionaire (Article 13)

Among other general obligations applied to the concessionaire for project implementation, it is noted that the law includes the obligation to (i) collect a tariff that is not higher than the Cabinet approved amount and (ii) hire Panamanian professionals and labor that are at least 90% of the total employees.

7) Fiscal Benefits for Concessionaire, Financial Institutions and Investors (Articles 23 and 24)

Fiscal benefits for the concesionaires, their shareholders and lenders, such as exemption of import tax and income tax, are determined in the said articles.

(3) Project Scheme Alternatives for the Line-3 Project

Based on the project's features and the international experience in PPP's in urban rail transit, probable project scheme alternatives for the Line-3 project are illustrated as follows. Table 8.15 below summarizes roles played by the public and private partners in each alternative.

Table 8.15 Project Scheme Options (Draft)

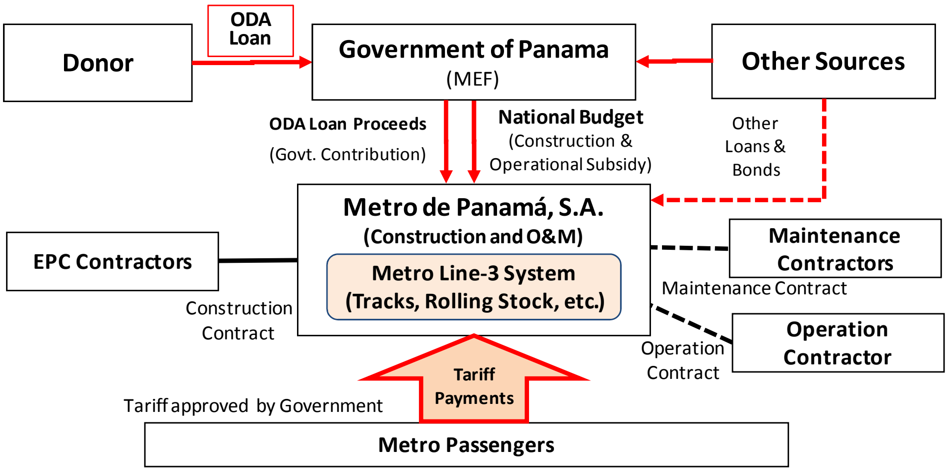
Scheme Option				Design	Build	Finance	Operate
1	Public Investment and Operation		Pub.	✓	✓	✓	✓
			Pvt.	-	-	-	-
2	Concession Scheme (Initial Investment by Government)		Pub.	✓	✓	✓	-
			Pvt.	-	-	-	✓
3	BOT/BTO Scheme (Initial Investment by the Private)		Pub.	-	-	-	-
			Pvt.	✓	✓	✓	✓
4	Vertical Separation (BOT/BTO for Rolling Stock and M&E)	Rolling Stock and M&E works	Pub.	-	-	-	-
			Pvt.	✓	✓	✓	✓
		Civil Works	Pub.	✓	✓	✓	✓
			Pvt.	-	-	-	-
5	Public Operation with Private Investment		Pub.	-	-	-	✓
			Pvt.	✓	✓	✓	-

Source: JICA Study Team

1) Alternative 1: Public Investment and Operation

As stated above, the public operation under public investment with ODA loan is the most probable alternative for project implementation (See Figure 8.5). The private sector's involvement is limited to constrcution of the metro system and some maintenance and operational activities on an outsourcing basis. All the financing requirement for the initial investment is under the government's responsibility. In further analysis, this scheme is regarded as the base case scenario.

In this scheme, the initial investment for construction is made by Metro de Panamá, S.A. using ODA loan and the government's subsidy. Donor's ODA loan is borrowed by the government. National budget may be applied to a part of the construction cost. Metro de Panamá, S.A. will construct the entire system through contractors. The corporation will be responsible to operation of the whole Line-3 system. Some maintenance and operation works may be outsourced to contractors. The corporation will collect the passenger tariff to cover its capital and operational expenditure. Since the affordable tariff is set by the government, considerable operational subsidy from the government is anticipated.



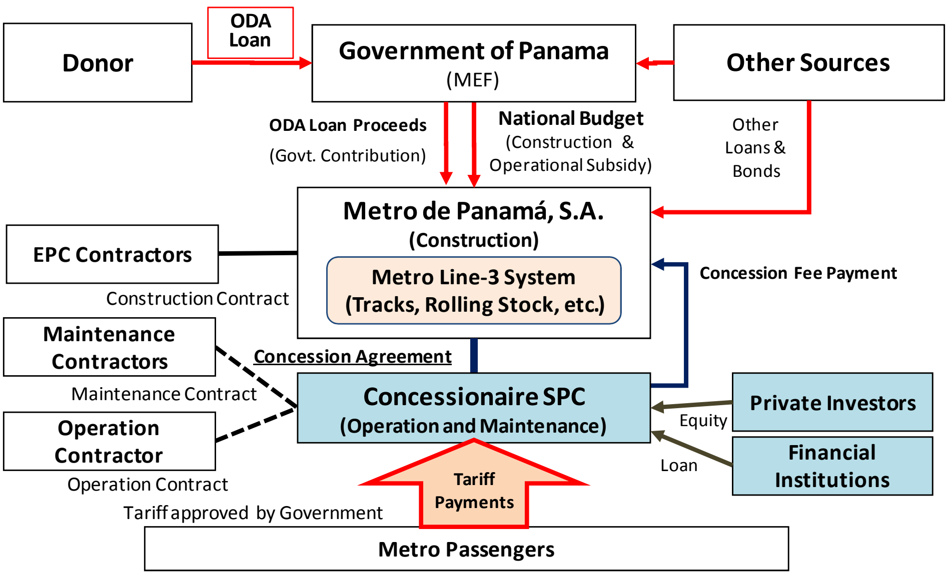
Source: JICA Study Team

Figure 8.5 Public Investment and Operation

2) Alternative 2: Concession Scheme

The public investment for this scheme is implemented in the same manner as in the first option. This option involves concession of the metro system which enables the private sector operator to operate the whole metro system for the long run based on the Administrative Concession Law; thereby better operational efficiency is expected (See Figure 8.6). However, the private sector investment in construction is not involved in the scheme. The government borrows ODA loan and Metro de Panamá, S.A. constructs the entire project scope; and then concession of the whole system is granted to a private concessionaire for its operation. The concessionaire SPC will operate and maintain the entire system and collect passenger tariff. Concession fee will be paid by the concessionaire to the Public to cover a part of the public investment.

There are two models applicable to this scheme. One is the fare-based concession, where the private concessionaire undertakes O&M of the Metro system based on the passenger fare revenue by taking the demand risk; and the other being the annuity-based concession, where the concessionaire undertakes O&M from the annuity payments from the public side q as predetermined in the contract.

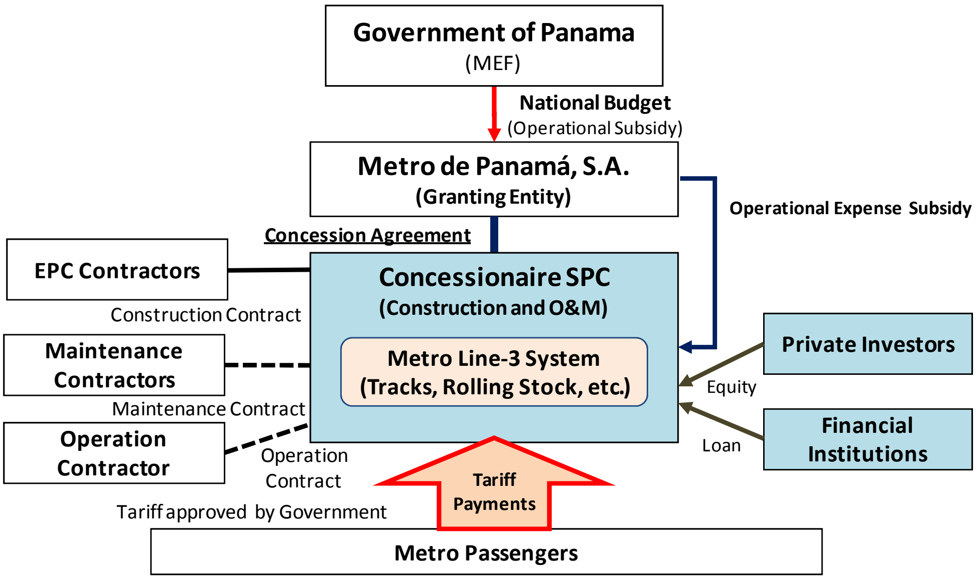


Source: JICA Study Team

Figure 8.6 Concession Scheme (Fare-based)

3) Alternative 3: BOT/BTO Scheme

In this alternative Metro de Panamá, S.A. grants the concession of the construction, procurement and operation of the entire metro system for the long term (See Figure 8.7). Difference from the concession scheme above is that the private sector concessionaire (BOT/BTO operator) will be responsible for the financing and construction of the entire capital investment requirement. Because of the project's financial non-viability as shown in the METI F/S, government support mechanism such as subsidy on passenger tariff (operational expense subsidy) will be necessary to implement the scheme.



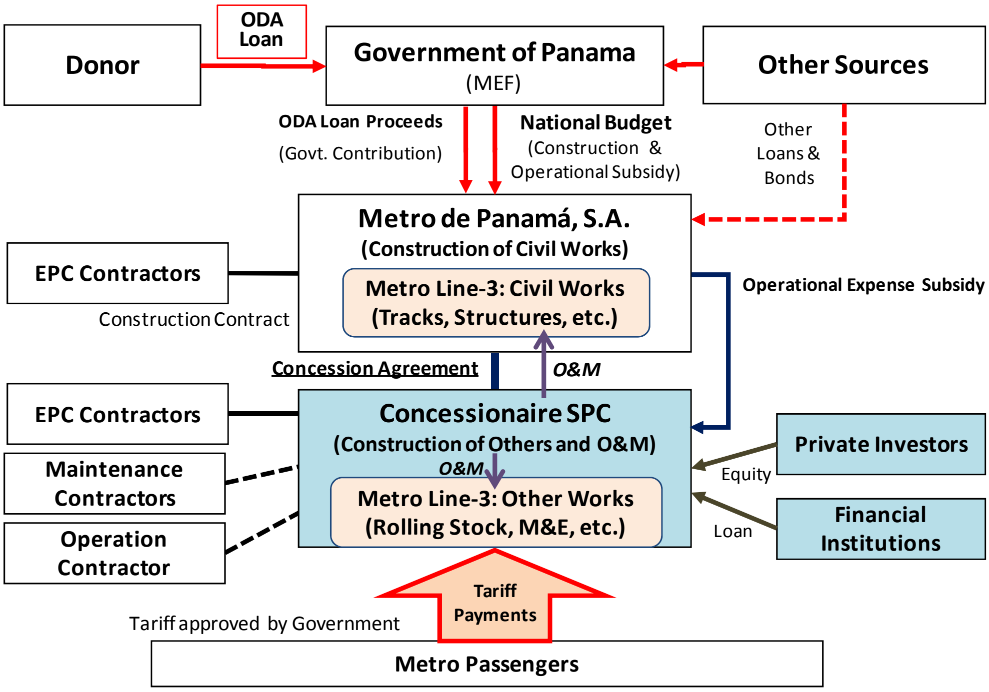
Source: JICA Study Team

Figure 8.7 BOT/BTO Scheme

4) Alternative 4: Vertical Separation

As a combination of the Concession Scheme (Alternative 2) and BOT/BTO (Alternative 3), in the vertical separation scheme the public entity constructs the civil works with concessional ODA finance while the private sector is responsible for the investment in rolling stock and M&E works as well as the operation and maintenance of the whole system and collects the passenger tariff, thereby reducing the financial burden of the government in the initial investment. Similar to the BOT/BTO Scheme, the operational expense subsidy from the Public is expected to bridge the project's viability gap.

Similar to the Concession Scheme, the Vertical Separation may take two models i.e. fare-based and annuity-based.

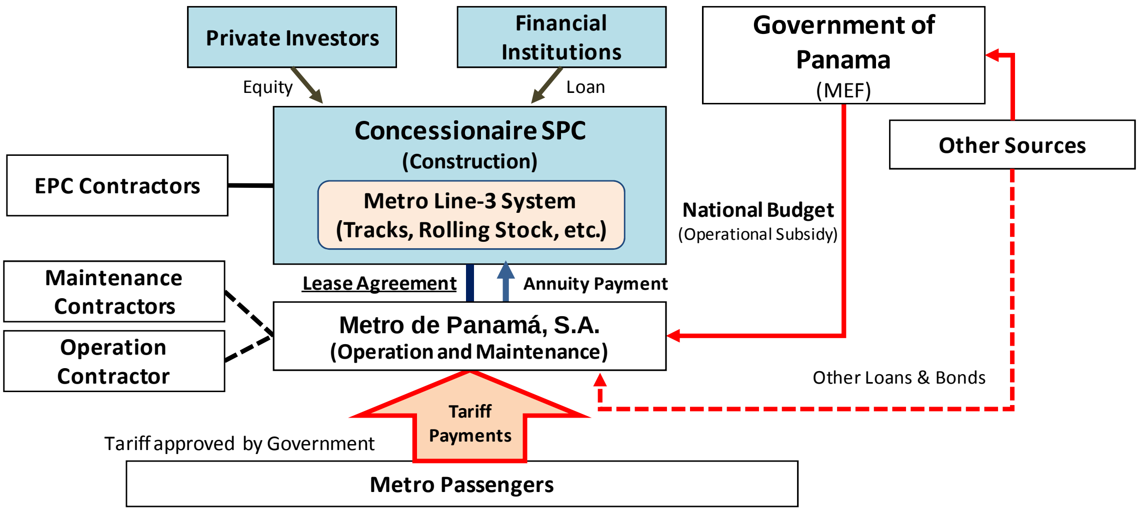


Source: JICA Study Team

Figure 8.8 Vertical Separation Scheme (Fare-based)

5) Public Operation with Private Investment

In the public operation with private investment scheme, the private sector partner undertakes construction of the entire project scope with its own financing. The public side (Metro de Panamá, S.A.) is responsible to the operation and maintenance of the Metro system and the collection of passenger fare. The capital investment and financing costs borne by the private will be recovered through the annuity payments from the public side which is supported by the operational expense subsidy provided by the government.



Source: JICA Study Team

Figure 8.9 Public Operation with Private Investment

(4) Comparison of Project Scheme Alternatives

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

1) Fiscal Requirement and Private Investsment and Operation

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

2) Passenger Fare Setting and Adjustment

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

3) Procurement

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

Table 8.16 Comparison of Project Scheme Alternatives

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

Source: JICA Study Team

8.6.3 Implications on PPP for Line-3 Project

- Any stakeholders have not expressed their intention to implement the Line-3 project in PPP. The public investment and operation with ODA loan finance is the primary setup for the project implementation.
- The project is financially not feasible and requires significant amount of government subsidy (See Section 18.5, Chapter 18 for details). Even with certain operational efficiency assumed in the PPP schemes, it is not very probable to achieve Value for Money compared to the public investment and operation scheme especially for the scheme alternatives involving initial investment by the private sector.
- Among PPP scheme alternatives, the Annuity-based Concession Scheme (Alternative 2-2) with public initial investment has less private efficiency requirement and would be a viable option for the government to achieve VFM through PPP.
- Current absence of predetermined fare setting regulation is a risk for the private partner's revenue source and is not suitable to fare-based PPP schemes. Annuity-based schemes are preferable in the current situation. Appropriate fare setting and adjustment regulation should be established by the government to ensure the project's sustainability.
- In case the government determines the PPP for the Line-3 project, the technical compatibility between public and private works and procurement efficiency must be further analyzed through market sounding of potential suppliers and operators as well as in-depth technical survey. Technical and transaction advisory is a must for the government to implement the further survey.
- Besides the debt service for the ODA loan, it is anticipated for the government to bear significant amount of recurrent government subsidy or annuity payments. Making such arrangements to enhance the financial viability for a PPP scheme is considered implicit debt in addition to the formal borrowings.

8.7 Implementation Schedule

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

To ensure fairness of procurement process as well as project implementation, information should not be disclosed for a fixed period.

Source: JICA Study Team

Figure 8.10 Implementation Schedule

Chapter 9 Institution and Organization

9.1 Implementation Structure

9.1.1 Railway project in Panama

There are two railway projects in Panama – Metro Project and Panama Canal Railway.

(1) Metro Project

1) Implementation structure

Four metro lines, including the Project, are proposed as described in Section 2. SMP was established under Ministry of the Presidency in 2009, prepared procedures, and broke ground for Line-1 in February 2011. The progress of the Metro project is shown in Table 9.1.

Table 9.1 The progress of the Metro project

Month, Year	Item
June, 2009	Creation of Secretary of Metro
July, 2009	Studies of Demand and Public Transport Modeling
September, 2009	Environmental Baseline
September, 2009	Field Surveys
December, 2009	IDB and CAF Finance Conceptual Design and Specification
January, 2010	Environmental Impact Study
January, 2010	Statement of Objections for Contractor Pre-qualification
May, 2010	Statement of Objections Trunkey Project
June, 2010	Statement of Objections to Project Management
August, 2010	Two Proposals for Turnkey Project
November, 2010	Winner Turnkey Project
November, 2010	Awarding Project Management
November, 2010	Concluding EIA
December, 2010	Order of Proceeding
February, 2011	Works Automatically Start

Source: Study Team referring to material of SMP web site

The legal framework of SMP enables such a quick response for the progress. It includes establishment of organization, land acquisition, bid, social environment, etc. And Metro de Panamá, S.A., hereinafter New Company, will be transferred the part of functions of SMP. New Company is the corporation 100% funded by government based on Low No. 109, 2013 on November 2013. The outline of legal items is shown in Table 9.2.

Table 9.2 Legal framework of SMP

Date	Law/ Decree/ Resolution	Note
July 2, 2009	Executive Decree No.150, Office of the President	• Establishment of SMP • To proceed the Metro Project in association with MOP
July 23, 2009	Executive Decree No.235, Office of the President	• Amendment to No.150, The powers of the Secretariat
January 7, 2010	Executive Decree No.1, MIVIOT	• SMP requested MIVIOT to take the necessary actions for establishing the borders of the Polygon of Influence of Panama Metro System Line-1. • It is necessary to proceed the Metro Project for estimating the scale of land acquisition by local survey.
April 14, 2010	Resolution of Cabinet No. 71, Office of the President	• Pre-bidding meeting • Procedure for selecting contractors
October 15, 2010	Low No.62	• Granting of fiscal exemptions to SMP and to the contractors and sub-contractors that participate in the construction of the Panama Metro. • Creation of Triparite Office, composed by National Customs Authority (ANA), MEF and SMP.
August 9, 2011	Resolution of Cabinet No.124	• Economic relief for affected owners of properties/ businesses
September 27, 2011	Low No.72	• Contractors and subcontractors exemption of several taxes • Amendment of 2010 Low No.62
November 29, 2011	Executive Decree No.528, MEF	• Contractors and subcontractors exemption of several taxes
November 25, 2013	Low No. 109	• Establishment of Metro De Panamá, S.A.

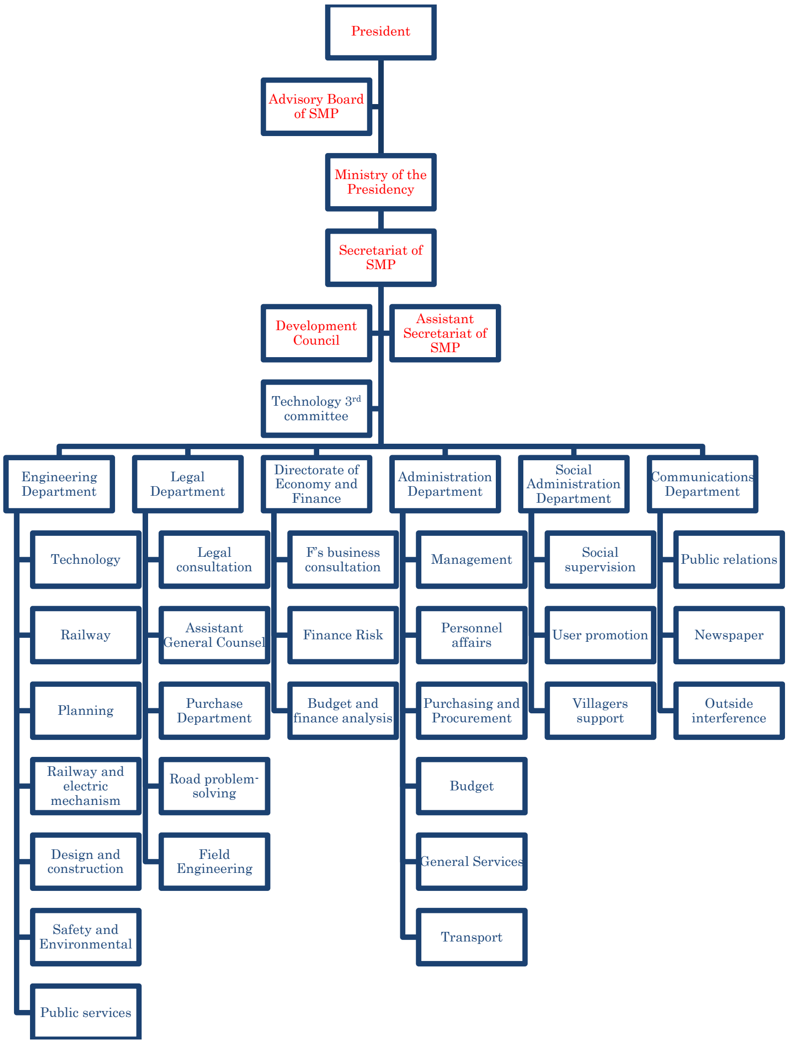
Source: Study Team referring to material of SMP web site

2) Jurisdiction of the executing agency

The mission of SMP is to provide services to improve living qualities by constructing a high speed, economical and safe transport system to meet the people's urgent needs in Panama. SMP is the implementation structure. And SMP operates by own and outsources maintenance to private contractor in Line 1 project. After the establishment of New Company, it was transferred the function of SMP.

3) Organization structure and human resources

The organization of SMP is composed by direction level and operation level. Each level owed clear jurisdiction and roles through integrated concept. The organization chart of SMP, Line-1 construction stage, is shown in Figure 9.1.



Note: Red character shows management division, Blue one shows operation division
Source: Study Team referring to material of SMP web site

Figure 9.1 Organization chart of SMP (Line-1 construction stage)

During Line-1 project execution stage, the number of staff is approx. 100. And the number of staff will be increased in the inauguration of Line 1. After the establishment of New Company, human resources are expected same of this assumption.

4) New Company

The outline of New Company, which is transferred the function of SMP, is shown below.

a) Establishment

The Low No. 109/2013, November 2013, regulates the establishment. First of all, Execution of article of association, appointment of officers, and selection of director general and auditor should be done as document works by Government of Panama in 160 days. And organization, byelaw and appointment will be done, the procedure, asset and valid contracts (employment contract, etc.) transferred to New Company, will be progressed step by step. It is assumed the completion date as the end of 2014. Concerning about Line 1, only constructed assets will be transferred to New Company, the contract of construction and loan will remain on MEF.

b) Financial Management

The assets of Line 1 will be transferred to New Company, and regarded as contribution in kind by GOP in capital. There is no plan to invest without it at the establishment. The loans will be kept to owe by GOP, there is no plan to transfer. In new project, including Line 3 project, MEF will owe the loan and asset will be transferred to New Company after completion. It is assumed to be possible "Implementation body: New Company, Borrower: MEF".

c) Organization structure and Human resources

Organization structure and Human resources of New Company are not clear. It is natural to consider that they are assumed as same as SMP, because transferred from SMP.

d) Others

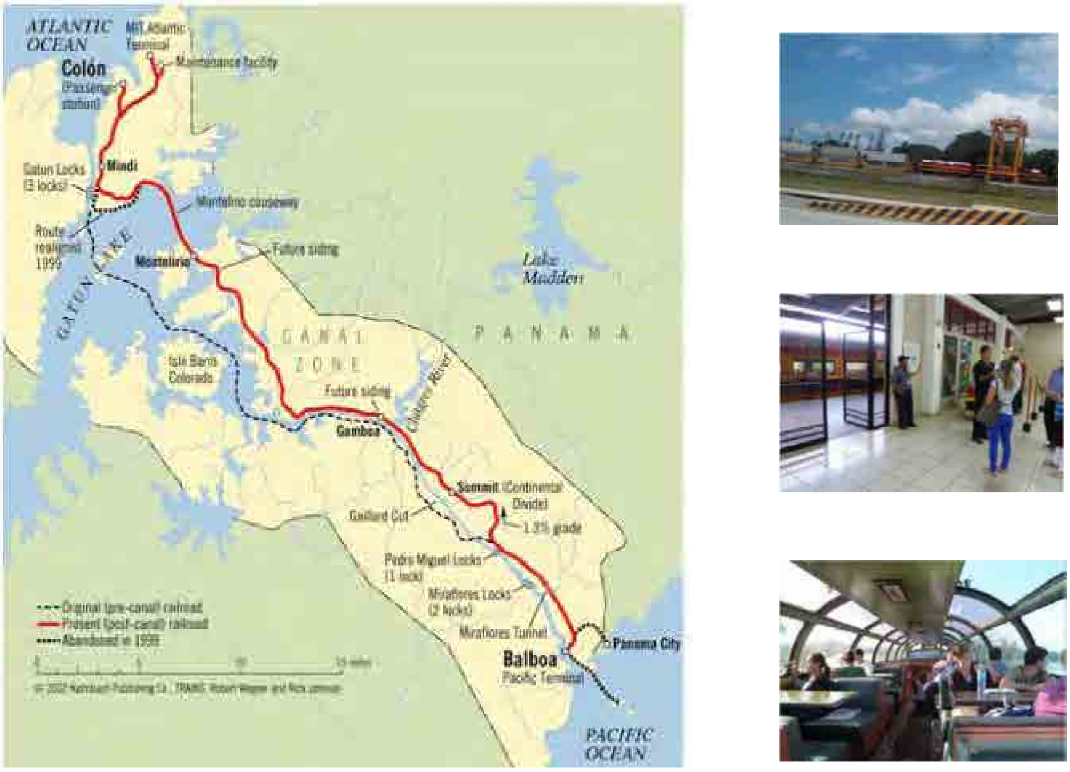
New company will have some new functions, which SMP do not have. One of them is PPP scheme, which is not constricted. And related activities with the transportation project, commercial development etc., which are expected to contribute the profit of New Company.

(2) Panama Canal Railway Company (PCRC)

1) Implementation structure

The history of railway in Panama is longer than Japan. Panama operates the railway since 1855 and Japan since 1872. The only operating line in Panama is a 77 km length between Panama City and Colon, which is operated by Panama Railway Company (PCRC). The origin of the line is the historical railway, the original route was changed caused by construction of Panama Canal. The line is operated by a modern facility since 2001. Railroaders in North America, Kansas City Southern Railroad and others, own the Company. The contract is Valid for a period of 25 years, with the option to extend it for an additional 25 year period. Under jurisdiction of Panama Maritime Authority (AMP), regulations depend on the Contract, which is Contract Law 15 of February 17, 1998 published in the Official Gazette no 23,485 of February 18, 1998.

Route map and photos are shown in Figure 9.2 .



Note:
Left: Route map, Right High: Freight facility and train, Right Middle: Ticket barrier, Right Low: High decker passenger wagon
Source: Study Team referring to material of PCRC web site

Figure 9.2 Route map and photos of PCRC

2) Jurisdiction of the executing agency

PCRC operates freight train and passenger train. The passenger train is operated only one return trip in weekdays. Diesel locomotives pull 6 wagons including one high decker wagon for tourists. Fare of passenger train in one way is 25/B for adult, 15/B for Child and 17.5 for retires.

9.1.2 The items to be considered in the Project

The points to keep in mind for the Project are shown as follows.

- The relationship between the Project and Line 1 project, after the function of SMP transferred to New Company.
- And the window of ODA in Panamanian side.
- The body in Panamanian side for installing the Monorail System.

The points are shown respectively as Implementation Structure and Operation and Maintenance (O&M) Structure.

9.2 Implementation Organization

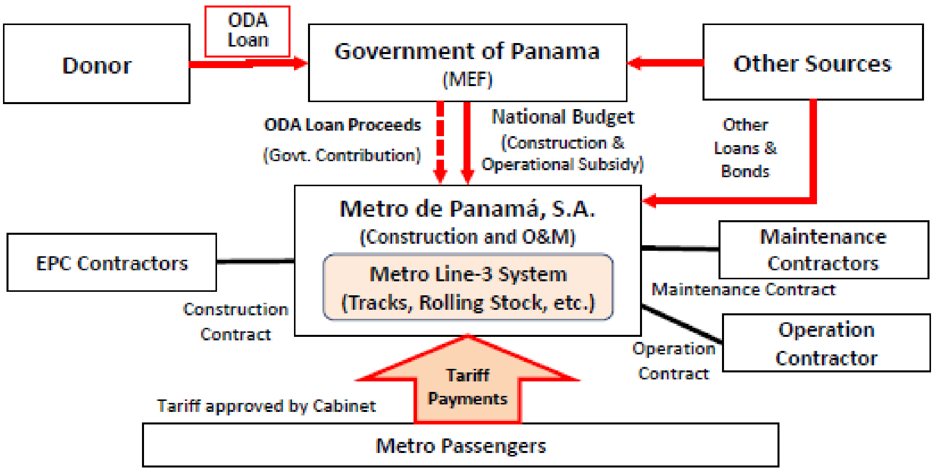
9.2.1 Implementation Scheme for the Project

The implementation scheme for Line-3 is assumed to be as same as that of Line 1 project although its implementation organization will be the successor of SMP. The manner

"Implementation: by SMP and New Company (after transition), Operation: by New Company with technical assistance by private company, O&M: outsourcing to Private by New Company" is supposed. The reason is shown as follows.

- A lot of cases of F/S in transport project, including Pre F/S study for Line 3 undertaken by METI earlier, can't reach the conclusion, both economically and financially feasible.
- The Project includes construction of Line-3 and 4th bridge crossing the Panama Canal. These are inseparable projects and expected huge costs for construction and maintenance.
- Line-3 is one of the parts of Metro network in Panama as described in Chapter 2. SMP is the organization for realize the Metro network.
- Line-1 project progresses steadily. It is possible to make use of human resources and know-how in Line-1 project. The same scheme as of Line 1 project seems to be smooth.
- The implementation organization of 4th bridge project is assumed as SMP, the jurisdiction of both projects is not complicated.
- SMP has no experience about monorail system. So private companies who have various experiences are helpful. The difference between the Project and Line 1 Project makes the technical assistance by private companies in the field of operation. Because Monorail System is unique and private companies who have an experience in the field of operation are helpful.

Figure 9.3 shows association chart of project executing agency.



Note: Operation Contract means technical assistance.
Source: Study Team

Figure 9.3 Association chart of project executing agency

9.2.2 Finance and Budget Structure

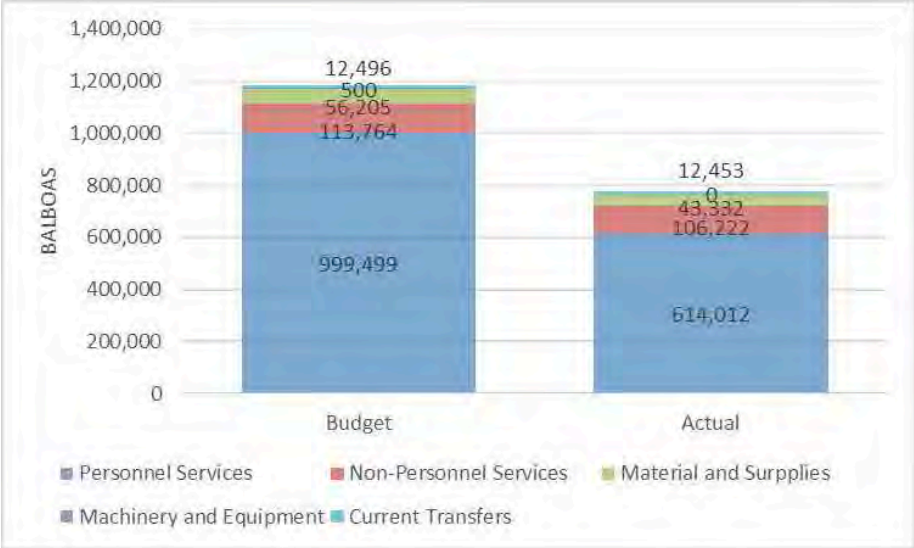
SMP under the Presidency has Ordinary Budget and Capital Budget.

(1) Finance/ Budget Record

The latest Finance/ Budget Record for SMP is shown as follows.

Ordinary Budget/ actual is shown in Figure 9.4 Personnel services 1,182,464/B is major part, which occupied 85% of 999,499/B. Actual figure 776,250/B is 66% of the budget.

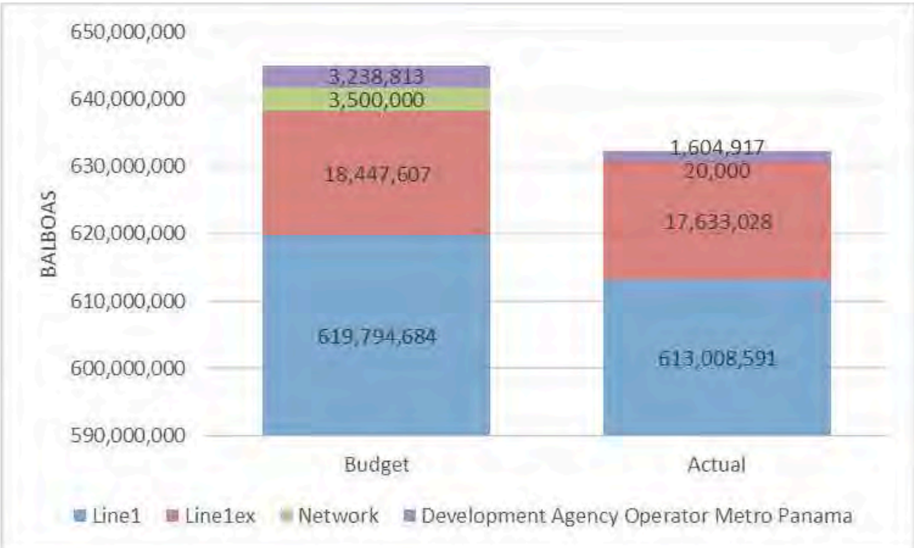
Personnel services 614,012/B occupies 79%. Other items are inconsequential and there is no items dissociated between the budget and the actual.



Source: Study Team referring to material of SMP

Figure 9.4 The ordinary budget/ actual in 2013

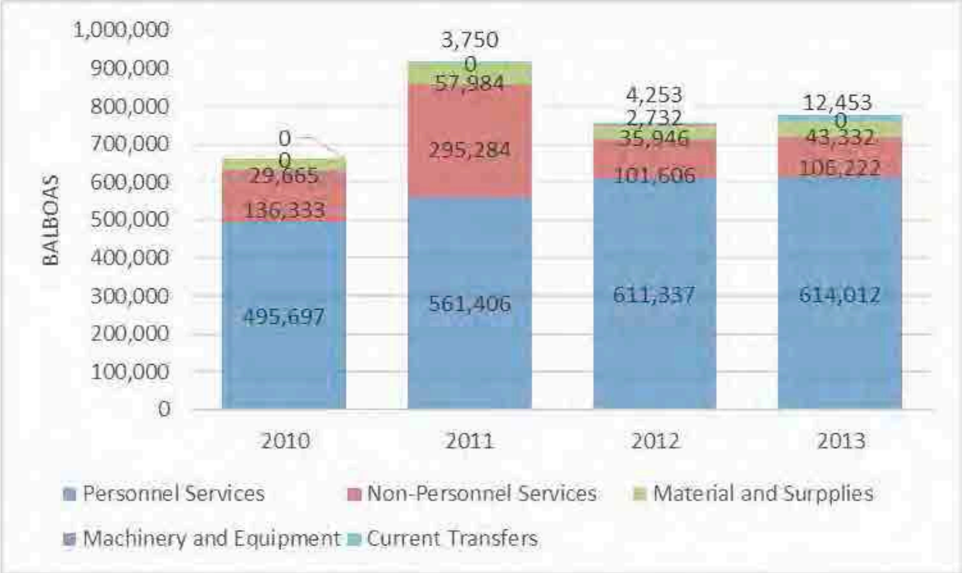
The Capital Budget/ actual is shown in Figure 9.5. Line 1 619,794,684/B occupies 96% of the budget 645,609,045. The actual 632,266,536/B reached 96% of the budget. The personnel services 613,008,591/B occupies 97%. Other items are inconsequential and there is no items dissociated between the budget and the actual as ordinary budget.



Note: Line1ex means Various Machinery and equipment, Administration Buildings and Other Installations.
Source: Study Team referring to material of SMP

Figure 9.5 The capital budget/ actual in 2013

The ordinary budget actual 2010-2013 is shown in Figure 9.6. The trend looks like slightly increasing and 918,444/B in 2011, Non-Personnel Services increasing, is remarkable. The major part is Personnel Services and occupied approx. 80 %, it is going to increase 24% in recent 3 years.



Source: Study Team referring to material of SMP

Figure 9.6 The ordinary budget actual 2010 - 2013

(2) Outline of the budget in 2014

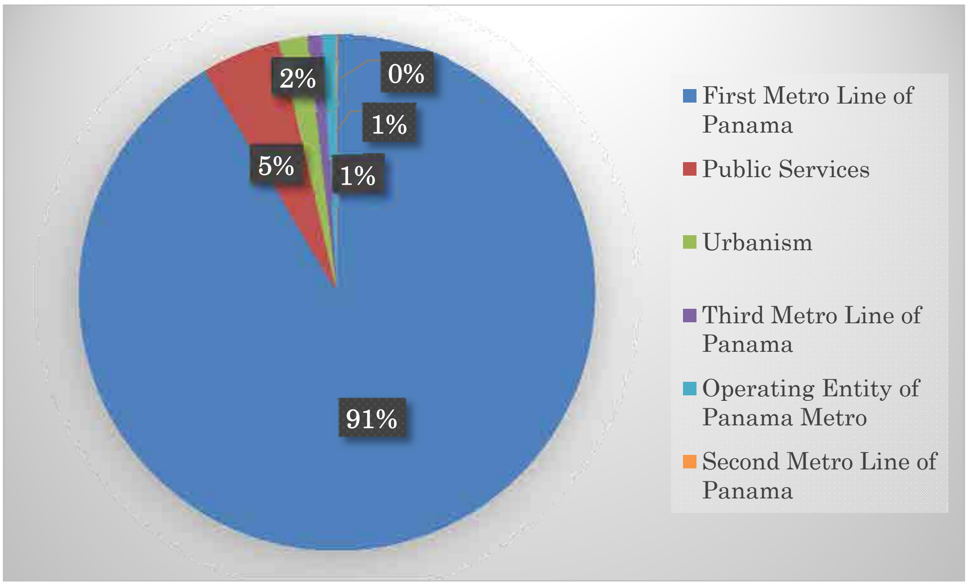
The outline of the budget in 2014, which was approved in 27th December 2013, is shown as follows.

1) Ordinary budget

30,000,000 /B is prepared as the ordinary budget for SMP in 2014. The amount is same as in 2010. The ordinary budget for SMP is increasing, 350,000,000 /B in 2011, 581,000,000 /B as progressing the Line 1 Project. It is assumed that the budget is same level as 4 years ago, approaching the completion.

2) Capital budget

560,211,000 /B is prepared for Metro Project, which is composed by 6 items. Line 1 project, Line 2 Project, Line 3 Project, public service, urbanism and operating entity of panama metro. The budget structure of metro project in 2014 is shown in Figure 9.7. The major part, 91%, is occupied by Line 1 project and the Project occupies 1%.



Source: Study Team referring to material of SMP

Figure 9.7 The capital budget in 2014

Functional transition from SMP to New Company, and the achievement after the inauguration of Line 1 are remarkable issues. Finance and budget structure of SMP and New Company should be followed.

9.2.3 Technical Standard

The Implementation Structure has less influence than Operation and Maintenance (O&M) Structure, in installing different system. The history of railway in Panama is long and modern operation is confirmed. SMP leads Line-1 project smoothly. So SMP and New Company, which is transferred the function of SMP, prove the capacity of adequate technical standard. It is possible to make use of know how and human resources acquired through Line 1 project.

9.3 O&M Organization

9.3.1 Concept of O&M Organization

(1) Jurisdiction

The new company is assumed to be established before the inauguration of Line 3. The O&M structure of "Operation by the new company with technical assistance by private companies, and maintenance by the new company by outsourcing it to private companies" is recommended. The reason is:

- SMP has an ability to operate urban railway through various preparing and training, in spite of Line-1 is not in operation.
- For example, preparing the manual for operation and maintenance or training the staff, driver, station staff, and maintenance personnel.
- The new company operates the Line-3 directly with technical assistance from private companies through accepting capital investment from the private companies or consignment to the private companies.
- Maintenance Contractor maintenances the Line.

Operation and Maintenance structure is positioned in Figure 9.3 shown above. In spite of the first installing Monorail System in Panama, if Japanese private companies, who have the know how in monorail system, join the project, it is expected going smoothly. Range, content, methodology and price standard for outsourcing to private company should be examined referring to Line 1 project.

(2) Technical Assistance Scheme

Cooperation of experienced private operator is necessary to ensure the technical assistance for the operation and maintenance of the monorail system. The following types of technical assistance could be applied to both operation and maintenance bodies.

1) Operation body

- Private operator contracts with operating body and provides technical support through operation and maintenance.
- Private operator capitalized to operating body and provides technical support about operation and maintenance.

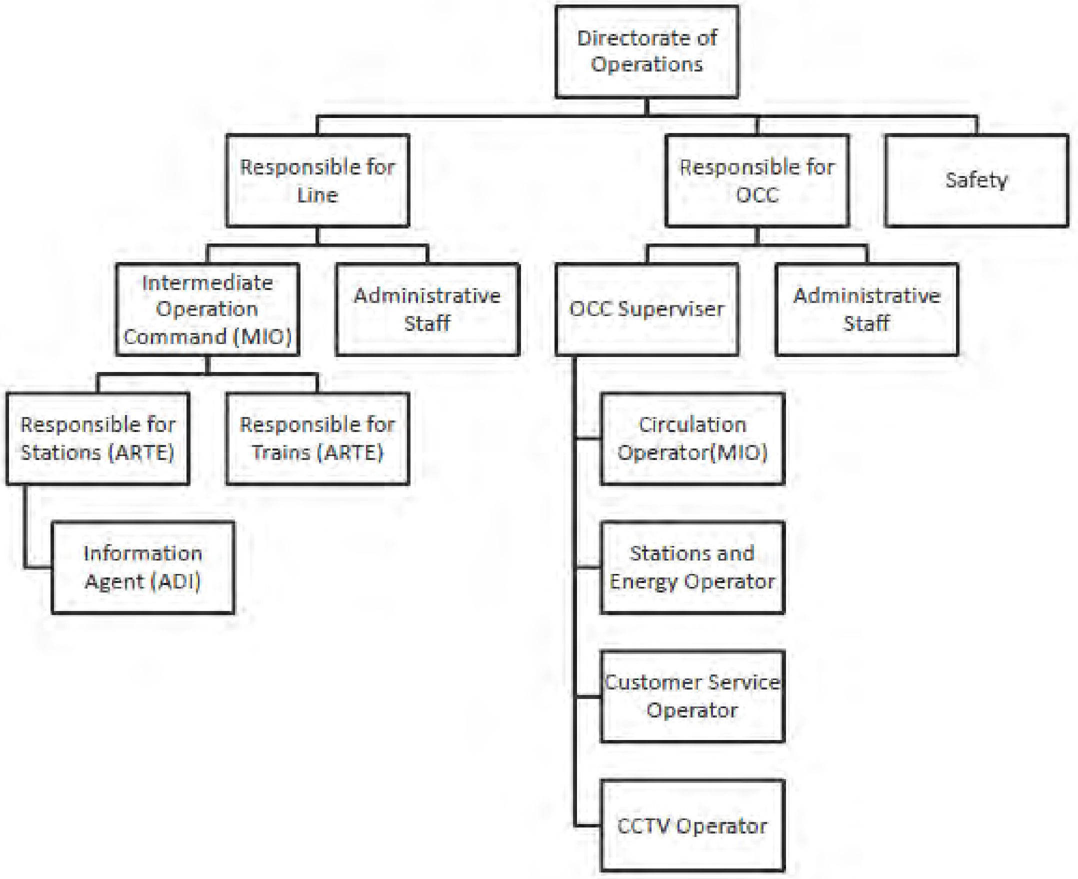
2) Maintenance body

- Private operator capitalized to maintenance body and provides technical support about maintenance.
- Private operator capitalized to maintenance body and provides technical support about maintenance.

Basically private sectors decide the participation of business by themselves, and government of Japan (GOJ) is preparing to establish new system for mitigation of private sectors' participation risks. The movement is expected to contribute for technical support. The enhancement joining Japanese experienced private sector is ensuring implementation of the Project, in spite of debut of monorail system in Panama. It is preferable referring to the precedent as Line 1, about coverage area, contents, methodology and standard of price in the field of participation by private sector.

(3) Organizational Structure

Since the structure of the new company has not been decided in Panama, it is assumed as same as modified organization plan in the operating stage of Line-1. Operation division and maintenance division are separated in Line-1. First in operation division, three parts are assumed as responsible for line, responsible for Operation Control Center (OCC) and Safety. The organization chart of the operation division for Line-1 is shown in Figure 9.8.



Note: MIO: Medium level staff, ARTE: Both task, train operator and station chief, ADI: Information agent
Source: Study Team referring to material of SMP

Figure 9.8 Line-1 / SMP Operational Organization Chart

Second in Maintenance division, staff assignment of New Company is assumed to supervise maintenance contractor. The field of maintenance is divided as Power, Rolling Stock, Signaling and Communication, Electromechanical system, Track and Catenary and so on.

(4) Personal Structure

The details of New Company is not unveiled, so the plan is shown after inauguration of Line 1 operated by SMP directly. In personal structure, approx. 210 personnel will be increased for preparation of Line-1 operation, including operation staff and supervisor for maintenance contractor. The breakdown is shown in Table 9.3for reference.

Table 9.3 The plan for increasing the number of staff for Line-1 operation

	Operation	Maintenance
Main Office	3	6
Operating Division	195 – 215	Private Sector

Source: Study Team referring to interview to SMP

And maintenance contractor divided two parts. One is integrated railway system and another is electromechanical and civil works. The former is owed by ALSTOM and the latter is owed by local companies. The structure and the number of staff is not clear. It is necessary to clear the items below.

Concerning about New Company, the items should be clear shown as follows.

- Scheme of New Company
- Applicability of the New Company for Line 3 Project
- Budget of New Company for personal expansion for Line 3 Project

9.3.2 Concept of Finance, Budget and Technical Level

(1) Operation division

It is preferable that integrated operation division drive Line 1, Line 2 and Line 3. The reason is shown as follows.

- Business purpose is common among Lines, in spite of different systems.
- New Company is planned as 100% GOP owned company. Yen Loan should be received directly, not through ministries.
- Integrated operation contributes the operation efficiency and user convenience. Also the consistency of space plan and fare system are secured.
- But it is required measures to secure the technical level, because monorail system is different system that of precedent Line 1. It is preferable to utilize Japanese know how by technical assistance.

(2) Maintenance division

It is assumed that New Company outsources to private company in field of maintenance. It is preferable to utilize Japanese know how in this division same as operation division. It secures adequate technical standards by attending Japanese participants. There are some examples of partial outsourcing in maintenance in Japanese monorail system.

9.4 Operation and Maintenance Plan

9.4.1 Precondition for Operation and Maintenance Plan

(1) Development Plan

Line-3 will start from Albrook, at the southwest of Panama City, and run to the western suburbs across the Panama Canal. The plan is to construct a 31.2km line in two phases. Phase 1 will construct a 25.8km section to Ciudad del Futuro to the west of Nuevo Arraijan, and Phase 2 will build the remaining approx. 5.4km section to La Chorrera.

The Phase 1 section will commence operation in 2022, but the commencement of the Phase 2 section has not yet been determined.

Table 9.4 Construction Sections and Development Plan

	Construction Section	Line length	Commencement
Phase 1	Albrook – Ciudad del Futuro	25.8 km	2022
Phase 2	Ciudad del Futuro – La Chorrera	Approx. 5.4 km (Total: approx. 31.2km)	Undecided

Note:
1) This study mainly focuses on the Phase 1 section. The length of the Phase 2 section is a rough estimate.
Source: JICA Study team

(2) Operation and Maintenance Entity

In addition to the Line-3 monorail, there will be two rail-based public transportation systems in Panama City, namely Line-1 and Line-2. Line-1 is under construction while Line-2 is still under planning. The train service for Line-1 shall be directly operated by SMP and the maintenance work shall be subcontracted to the private sector under SMP supervision.

This operation and maintenance scheme for Line-1 could also be applied to Line-3, however, a concession agreement for subcontracting both operation and maintenance to the private sector could be an alternative. Additional studies shall be required to select the appropriate operation and maintenance entity for Line-3.

(3) Train Operation Method

Train Operation: Automatic operation by ATO (However, one driver with the qualification for manual operation is still required to be on board)

Operation Control: Centralized control by the Operation Control Center (OCC) in the Depot. Because OCC of Line-1 has sufficient space to increase its capacity to control both Line-2 and Line-3 in the future, OCC of Line-3 can be integrated into Line-1 depending on the operation entity.

Signaling System: Moving block by CBTC

(4) Concept of Fare Structure

The fare structure for Line-3 needs to be studied in relation to the fare structure of the existing and future public transportation systems in Panama City, including the suburban area, and the transfers between these systems. Presently, the general public transportation system in the city is the Metro Bus. Line-1 has just opened in April 2014, while Line-2 will also be introduced in the future.

Table 9.5 summarizes the basic information about the fare structure, fare level and transfer charges of Metro Bus, Line-1 and Line-3. The Metro Bus adopts a flat-rate structure and basically allows free transfers between normal buses. Line-1 started fare collection at a flat fare of USD 0.35 from June 15, 2014.

Because Line-3 is longer than Line-1 (approx. 26 km in Phase 1 alone, and more than 30 km in Phase 2), in addition to the flat-rate of Metro Bus and (supposedly) of Line-1, a distance-based structure, which is generally adopted by Japanese railway operators, should also be considered. The distance-based structure is a relatively fair approach to transit users. Additionally, due to the length of Line-3, greater profitability can be expected from a distance-based fare. However, it should be noted that the final decision on the fare structure also depends on whether SMP shall directly manage the service operation or subcontract it to the private sector.

Although Line-1 is scheduled to open shortly, its fare system is still under study indicating that sufficient time and research are needed for making the final decision. The same holds true for Line-3 where a detailed study is necessary to select the appropriate fare system.

Table 9.5 Concept of Fare Structure for Line-3

	Metro Bus	Line-1	Line-3 (Possible alternative)
Fare system	Flat rate	Flat rate	• Flat rate • Distance-based rate
Fare level	Normal bus: USD 0.25 Express bus: USD 1.25	USD 0.35	• USD 0.65 for the demand forecast
Transfer Charge	• Mutual transfers between normal buses: free within 40 minutes • Transfers between normal bus and express bus: additional US$1.00 • Transfers between bus and Line-1: not integrated		• Free transfer to both Line-1 and Metro Bus • Free transfer to Line-1 and discount transfer to Metro Bus (certain amount is deducted from total sum) • Discount transfer to both Line-1 and Metro Bus • Completely separate fare system (No discount)

Note: Fare system of Line-2 is still under planning and the suburban bus service has a completely separate fare system.
Source: JICA Study team

(5) Maintenance Work on the 4th Bridge

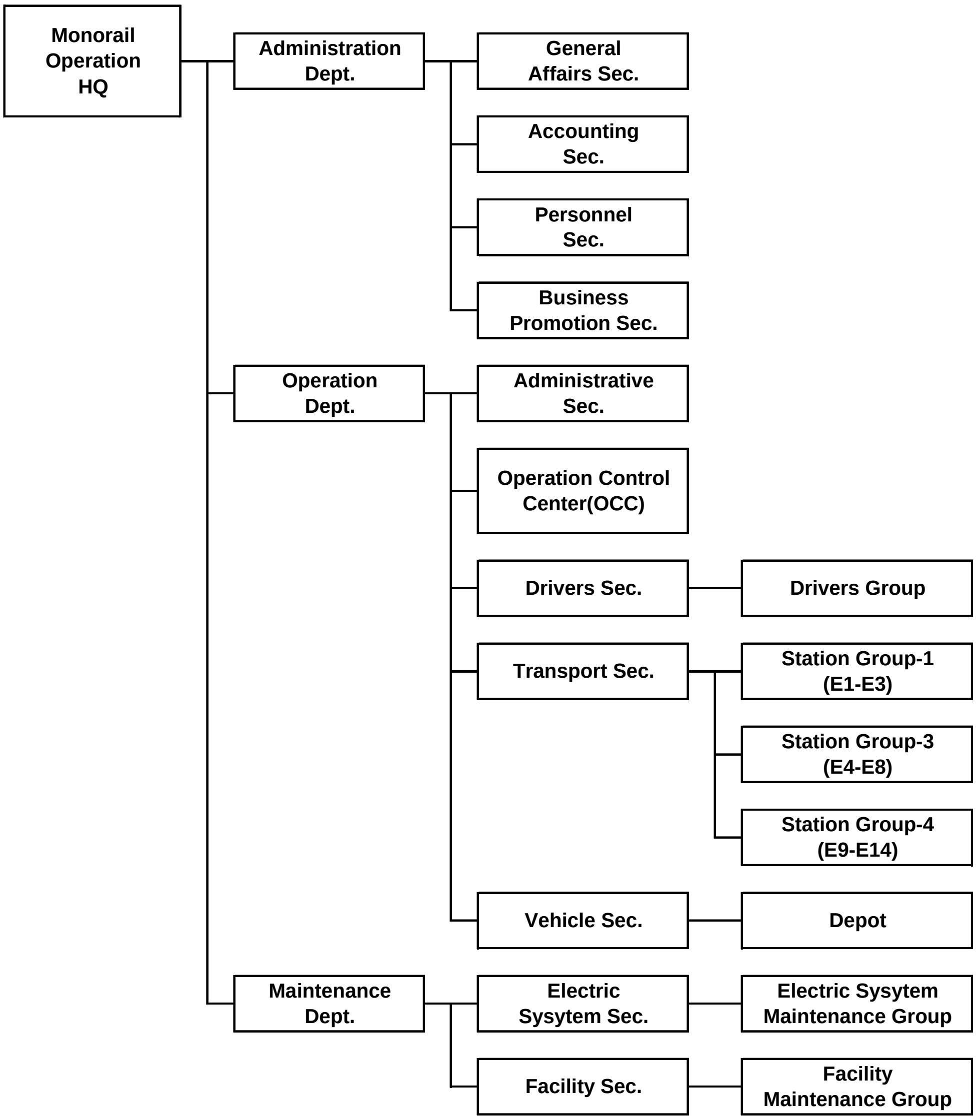
The Line-3 operator will be responsible for the maintenance work of girders and power feeding facilities of monorail on the 4th Bridge, while other parts of the bridge structure including the superstructure for monorail track will be maintained by the responsible agency of the 4th Bridge.

9.4.2 Organization and Personnel Plan

(1) Organizational Structure

As mentioned in section 8.3 above, the organizational structure of O&M for Line-1 is divided into an Operation Division and Maintenance Division and each division is further divided into sections with a specific area of responsibility. For example, Train Operation, Stations, OCC and Rolling Stock sections are under the Operation Division, and Civil, Electromechanical, Signaling and Communication sections are in the Maintenance Division. However, maintenance is subcontracted to the private sector in Line-1.

Based on the above, this study presents a recommendation for the O&M organizational structure for Line-3 as shown in Figure 9.9. This structure is widely popular among Japanese railway operators including monorail operators.



Source: JICA Study Team

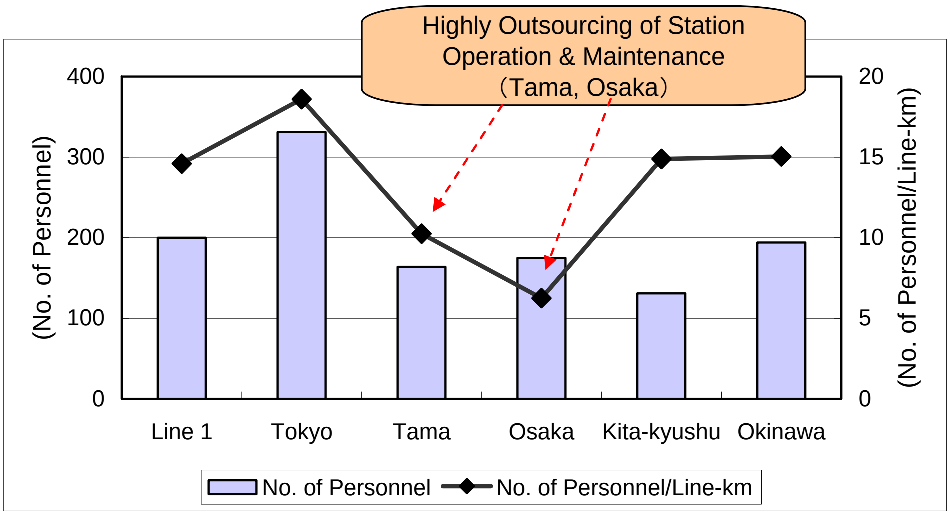
Figure 9.9 Organizational Structure of Monorail Operator (Recommendation)

(2) Personnel Plan

1) Concept of Personnel Plan

The personnel plan for Line-3 is formulated with reference to the personnel plan of Line-1 and Japanese monorail operators. Figure 9.10 illustrates the comparison of the number of personnel in several Japanese monorail operators. The range is from approx. 130 persons as a minimum (Kita-Kyushu Monorail) to approx. 330 persons as a maximum (Tokyo Monorail) depending on their commercial scale. However, except for the Tama Monorail and Osaka Monorail where more station O&M are outsourced, the number of personnel per Line-km is in the range of 15 to 19 persons/km.

The result reveals the similarity between Line-1 and Japanese monorail operators. Therefore, the personnel plan for Line-3 is calculated based on the actual data of Japanese monorail.



(Note) No. of Personnel of Line 1(200 persons) is rough estimate.

Source: SMP, Railway Statistics Annual Report 2010

Figure 9.10 Comparison of Number of Personnel between Line-1 and Japanese Monorails

2) Calculation Method for Required Number of Personnel

As shown in Table 9.6, the number of personnel is calculated for each section illustrated in the organizational structure (Figure 9.9) with the actual data of Japanese monorail operators.

Among the monorail lines operating in Japan, five lines, which are straddle type and provide urban transport services, are selected and their actual data in fiscal 2010 are examined (refer to Table 9.7). For Line-3, the unit numbers of the Tokyo Monorail are adopted because its transport volumes and capacity are similar to Line-3. However, regarding the track and electrical maintenance staff, the unit numbers of the Osaka Monorail are adopted since its operation length is similar to that of Line-3, and because the Tokyo Monorail has been operated for considerably more years and its facilities are older.

Table 9.6 Type of Profession and Unit Numbers for Estimating Number of Personnel

Type of Profession	Unit Number for Quantity
Driver	Per Average Train-km a Day (by 1 driver)
Station Staff	Per Number of Stations
Other Operation Staff (OCC)	Per Average Number of Train Frequency a Day
Track Maintenance Staff	Per Line-km
Electric Maintenance Staff	Per Line-km
Rolling Stock Maintenance Staff	Per Number of Cars
Staff in Headquarter	Ratio to Total Number of Field Staffs (Above Profession)

Source: JICA Study Team

Table 9.7 Actual Unit Number of Personnel of Major Japanese Monorail Operators

	Item	Unit/Explanation	Formula	Tokyo	Tama	Osaka	Kita-kyushu	Okinawa	Remarks
Number of Personnel	Driver	Persons	A	84	53	62	22	35	
	Station Staff	Persons	B	105	29	12	63	88	
	Other Operation (OCC)	Persons	C	18	13	19	--	20	
	Track Maintenace	Persons	D	9	5	20	4	7	
	Electric Maintenace	Persons	E	26	20	14	11	8	
	Rolling Stock Maintenace	Persons	F	32	10	15	8	8	
	Sub-Total	**Persons**	**G=A～F**	**274**	**130**	**142**	**108**	**166**	
	Staff in Headquarter	Persons	H	57	34	33	23	28	
	Total	**Persons**	**I=G+H**	**331**	**164**	**175**	**131**	**194**	
Amount Concerning Number of Personnel	Line-km	km	J	17.8	16.0	28.0	8.8	12.9	
	Train-km	km per Day	K	9,099	3,693	6,258	1,827	2,868	
	Car-km	1000km per Year	M	19,929	5,390	9,136	2,667	2,094	
	Ave. Number of Train Frequency	Train-km/Line-km	N=K/J	511.2	230.8	223.5	207.7	222.4	
	Number of Cars	Cars	P	120	64	84	40	24	
	Number of Stations	Stations	Q	10	19	18	13	15	
Unit Number of Personnel	Driver	Average Driving-km per Day	R=K/A	108.3	69.7	100.9	83.1	82.0	
	Station Staff	per Number of Stations	S=B/Q	10.500	1.526	0.667	4.846	5.867	
	Other Operation (OCC)	per Ave. Number of Train Frequency	T=C/N	0.0352	0.0563	0.0850	--	0.0899	
	Track Maintenace	per Line-km	U=D/J	0.506	0.313	0.714	0.455	0.543	Selected Osaka *1
	Electric Maintenace	per Line-km	V=E/J	1.461	1.250	0.500	1.250	0.620	Selected Osaka *1
	Rolling Stock Maintenace	per Number of Cars	W=F/P	0.267	0.156	0.179	0.200	0.333	
	Staff in Headquarter	% for Sub-Total	Y=H/G	20.8%	26.2%	23.2%	21.3%	16.9%	
	Total	**No. of Personnel/Line-km**	**Z=I/J**	**18.6**	**10.3**	**6.3**	**14.9**	**15.0**	

（Note）Actual records of Tokyo Monorail are selected as the unit number for estimating the number of personnel in Line 3, because its train operation frequency, number of passengers, distance between stations and commercial speed are similar to Line 3 among 5 sumples.
*1 However, concerning track and electric maintenance staff, actual records of Osaka Monorail are selected bcause Tokyo Monorail has been operating for almost 50 years so its track and electric facilities are old.

Source: Railway Statistics Annual Report 2010

3) Calculation Results

The calculation results are indicated in Table 9.8. The number of personnel is 356 persons in the inauguration year 2020. As the train frequency and the number of cars increase, the number grows to 421 persons in 2050, that is approximately a 18% increase from 2020.

Table 9.8 Calculation Results for the Number of Personnel in Line-3 (Phase1)

Item	Profession/Amount	Unit	Formula	2020	2025	2030	2035	2040	2050
Number of Personnel (According to Profession)	Driver	Persons	A=k/a	90	90	95	95	95	102
	Station Staff	Persons	B=b×m	116	147	147	147	147	147
	Other Operation (OCC)	Persons	C=c×n	14	14	14	15	15	15
	Track Maintenace	Persons	D=d×h	19	19	19	19	19	19
	Electric Maintenace	Persons	E=e×h	13	13	13	13	13	13
	Rolling Stock Maintenace	Persons	F=f×j	42	47	49	50	50	52
	Sub-Total	Persons	G=A～F	294	330	337	339	339	348
	Staff in Headquarter	Persons	H=G×g	62	69	71	71	71	73
	Total	**Persons**	**Q=J+K**	**356**	**399**	**408**	**410**	**410**	**421**
	Total per Line-km	Persons/km	R=Q/k	13.8	15.5	15.8	15.9	15.9	16.3
Unit Number of Personnel	Driver	Ave. Driving-km/Day	a	108.3	108.3	108.3	108.3	108.3	108.3
	Station Staff	Persons/Stations	b	10.5	10.5	10.5	10.5	10.5	10.5
	Other Operation (OCC)	Persons/Ave. Train Frequency	c	0.0352	0.0352	0.0352	0.0352	0.0352	0.0352
	Track Maintenace	Persons/Line-km	d	0.714	0.714	0.714	0.714	0.714	0.714
	Electric Maintenace	Persons/Line-km	e	0.500	0.500	0.500	0.500	0.500	0.500
	Rolling Stock Maintenace	Persons/Cars	f	0.267	0.267	0.267	0.267	0.267	0.267
	Staff in Headquarter	% for Sub-Total	g	20.8%	20.8%	20.8%	20.8%	20.8%	20.8%
Amount Concerning Number of Personnel	Line-km	km	h	25.80	25.80	25.80	25.80	25.80	25.80
	Number of Cars	Cars	j	156	174	180	186	186	192
	Train-km per Day	Train-km/Day	k	9,685	9,719	10,225	10,274	10,274	10,965
	Number of Stations	Stations	m	11	14	14	14	14	14
	Ave. Number of Train Frequency	Train Frequency/Day	n	375.4	376.7	396.3	398.2	398.2	425.0

（Notice）Station E6, E9 and E13 will be commenced in 2025.

Source: JICA Study Team

9.4.3 Maintenance Plan

(1) Basic Policy

The basic policy for the maintenance of railways in Japan, including monorails, is the preventive maintenance method. Based on past experiences and records, worn parts are replaced before trouble occurs. However, European and American railways adopt a different policy for their maintenance work. They replace parts when trouble occurs. Regarding Line-1, since ALSTOM is in charge of maintenance the European and American policy will be adopted.

Considering the nature of monorail systems, troubles should be predicted and coped with in advance based on preventive maintenance, because it takes longer to evacuate passengers from monorails than from normal railways in case trouble arises between stations. For this purpose, the regular maintenance system for monorails in Japan can be referred to, such as the plan for daily inspections, monthly inspections, inspection of important (critical) parts and overhaul. These inspections are compulsory by government regulations in Japan.

(2) Maintenance Method Based on Japanese Monorail System

1) Rolling Stock

Table 9.9 shows the requirements for periodic vehicle inspections prescribed by Japanese decree. These inspections provide preventive measures for achieving high safety in operation.

Furthermore, the inspection of tires, which are quite different from the wheels of normal rail systems, is important in monorail operation. Although tire inspection is not stipulated by decree, in the Tokyo Monorail tires are inspected every 3 weeks.

Table 9.9 Periodic Inspections of Vehicles

Inspection category	Main contents of inspection	Inspection Cycle	Approx. time required ※1
Daily Inspection	☐ Aspect of signal system, braking function ☐ Bogie, Running devices ☐ Cab driving equipments ☐ Door opening functions	**3 days**	Approx. 0.5hours/vehicle
Monthly Inspection	☐ Internal inspection of major parts of equipment without dismounting but with the lid off ☐ General function test after equipment inspection	**3months**	Approx 0.75days/vehicle
Inspection of Important Part	☐ Inspection and maintenance of major equipment dismounted from vehicle body. Some of them are overhauled.	**Earlier of 4 years or 600,000km**	Average 10 days/vehicle
Overhaul	☐ Inspection and maintenance of equipment dismounted from vehicle body and overhauled. ☐ Maintenance for keeping safety operation till next maintenance time by replacing all worn and torn parts.	**8 years**	

*1 Varies depending on the availability of facilities and the number of personnel engaged
Source: JICA Study Team (Based on Japanese Regulations)

Source: JICA Study Team

Figure 9.11 Daily Inspection (Tama Urban Monorail)

2) Facilities

An outline of the regular inspections required for track facilities and electrical equipment is shown in Table 9.10 and Table 9.11. Regarding the facilities, the items to be inspected and the inspection cycles are determined by corresponding regulations, but monorail operators often keep a shorter inspection cycle than that required by law.

Due to the particular characteristics of the monorail track, track maintenance is done with special maintenance vehicles. There are several types of maintenance vehicles such as a mobile work-shop, crane car, towing car and clearance car. Since the maintenance work is done during night hours without traction power, maintenance vehicles are capable of running by battery power or diesel engine (Figure 9.12).

Maintenance vehicles are normally kept in the depot during the day. During the maintenance work hours (approximately 5 hours) between the last train of the day and the first train of the next day, maintenance of the track facilities is done with the procedure “deployment - maintenance work at site - return to depot.”

Table 9.10 Overview of Inspection/Maintenance of Track facilities, Railway structures and Station equipment

Inspection category	Main contents of inspection	Inspection Cycle
Inspection tour of main line	☐Inspection of main line	**Everyday** （combined with inspection of contact line）
Track	☐Track	**1 year**
Track structure	☐Bridge, Tunnel and other track structures	**2 years**
Elevating Machines	☐Elevating machines such as Elevator and Escalator	**6 months to 1 year**
General building structures	☐Station building, Platform ☐Passenger Screen Door	**Properly dealt**
Station Passenger Facility	☐Operation Check and Cleaning of Automatic Vending Machine and Automated Fare Collection Equipment ☐Replacement of wearing parts and Insulation Test etc.	**Properly dealt**
Others	☐Inspection and commissioning upon construction, renovation and restart from operation halt ☐Signage and record of inspection	**Properly dealt**

Source: JICA Study Team (Based on Japanese Regulations)

Table 9.11 Overview of Inspection/Maintenance (Repair) of Electrical Equipment

Inspection category	Main contents of inspection	Inspection Cycle
Power Equipment	☐Catenary (main line)	**Everyday** （combined with track inspection）
	☐Contact Line, Switchgear, ,automatic circuit-breaker, arrestor, protectionsequence machine of substation ☐Critical portions of electrical equipment other than above ☐Other electrical equipment	**1 year** **1 year** **2 years**
Signaling System	☐Safety Equipment such as Signal equipment, Interlocking equipments, switch & lock movement equipment	**1 year**
Communication System	☐Communication equipment	**1 year**
Various Measuring instruments	☐Measuring instruments attached to power equipment, communication equipment and other safety equipment	**1 year**
Disaster Prevention Equipment	☐Fire-alarm box, Sprinkler, Smoke detector, extinguisher etc,	**Six months (visual and functional inspection)** **1 year（overall inspection）**
Other instruments	☐Station monitoring equipment, Signage equipment, lighting equipment etc.	**Properly dealt**
Voluntary Inspection	☐Filter cleaning of Substation, Painting of outside equipment etc.	**Properly dealt**
Others	☐Inspection and commissioning upon construction, renovation and restart from operation halt ☐Signage and record of inspection	**Properly dealt**

Source: JICA Study Team (Based on Japanese Regulations)

Mobile Work-Shop (Diesel Engine)
[Tokyo Monorail]

Mobile Work-Shop (Coupled with Crane Car)
[Okinawa Urban Monorail]

Inside Mobile Work-Shop
(Visual Inspection of Track)
[Okinawa Urban Monorail]

Inspection of Track Bolts
[Okinawa Urban Monorail]

Source: Tokyo Monorail, Okinawa Urban Monorail

Figure 9.12 Maintenance Using Special Maintenance Vehicles for Monorail

9.4.4 Estimation of O&M Cost

(1) Direct Personnel Cost

Direct personnel cost is estimated by multiplying the number of staffs by year, which was estimated in 8.4.2 (2), with average unit cost of personnel cost.

1) Unit Cost of Personnel Cost

Applied personnel unit cost is estimated by referring the estimation result of O&M cost for Line1 (August 2012) as shown in Table 9.12.

Table 9.12 Unit Personnel Cost by Profession

Profession	Method for Setting Unit Cost (Notes)	Monthly Unit Cost (USD/month)	Yearly Unit Cost (USD/year)	Yearly Unit Cost (JPY 1000/year)
Driver	Train Operator's price is applied	1,200	14,400	1,436
Station Staff	Weighted average of Station Chief's price and Station Operator's price is applied (20:80)	1,000	12,000	1,196
Other Operation (OCC)	OCC Operator's price is applied	1,600	19,200	1,914
Track Maintenance	Average of Maintenance of Integrated System's price and Station Maintenance's price is applied	1,400	16,800	1,675
Electric Maintenance		1,400	16,800	1,675
Rolling Stock Maintenance		1,400	16,800	1,675
Staff in Headquarter	Weighted average of Managers' price and Analysts' price is applied (20:80)	1,400	16,800	1,675

(Notes)
1. Mean value of "Low" and "High" of the Line1 cost estimation scenario is rounded off per USD 100.
2. Social costs are included in these unit costs.
Source: JICA Study Team (Referring the estimation result of O&M cost for Line1 (August 2012))

2) Estimation of Direct Personnel Cost

Summary of the direct personnel cost is shown in Table 9.13. The direct personnel cost, which is measured in annual term of 2010 price, is estimated at about USD 5.2 million, being equivalent to about JPY 520 million at the inauguration year 2020. In the final year of simulation 2050, about USD 6.2 million, being equivalent to JPY 610 million. The direct personnel cost will increase by 17% during 30 years.

Table 9.13 Estimated Direct Personnel Cost

Item	Profession	Unit Cost (USD/month)	Unit Cost (USD/year)	2020	2025	2030	2035	2040	2050
Personnel Cost (USD)	Driver	1,200	14,400	1,296	1,296	1,368	1,368	1,368	1,469
	Station Staff	1,000	12,000	1,392	1,764	1,764	1,764	1,764	1,764
	Other Operation (OCC)	1,600	19,200	269	269	269	288	288	288
	Track Maintenace	1,400	16,800	319	319	319	319	319	319
	Electric Maintenace	1,400	16,800	218	218	218	218	218	218
	Rolling Stock Maintenace	1,400	16,800	706	790	823	840	840	874
	Staff in Headquarter	1,400	16,800	1,042	1,159	1,193	1,193	1,193	1,226
	Total		**1000USD/year**	**5,242**	**5,815**	**5,954**	**5,990**	**5,990**	**6,158**
	Average Personnel Cost		1000USD/year	14.72	14.57	14.59	14.61	14.61	14.63
Personnel Cost (JPY)	Driver		1,435,680	129,211	129,211	136,390	136,390	136,390	146,439
	Station Staff		1,196,400	138,782	175,871	175,871	175,871	175,871	175,871
	Other Operation (OCC)		1,914,240	26,799	26,799	26,799	28,714	28,714	28,714
	Track Maintenace		1,674,960	31,824	31,824	31,824	31,824	31,824	31,824
	Electric Maintenace		1,674,960	21,774	21,774	21,774	21,774	21,774	21,774
	Rolling Stock Maintenace		1,674,960	70,348	78,723	82,073	83,748	83,748	87,098
	Staff in Headquarter		1,674,960	103,848	115,572	118,922	118,922	118,922	122,272
	Total		**1000JPY/year**	**522,588**	**579,775**	**593,654**	**597,243**	**597,243**	**613,992**
	Average Personnel Cost		1000JPY/year	1,468	1,453	1,455	1,457	1,457	1,458

（Note） Each year's price is expressed in base year cost (2010).
Source: JICA Study Team

(2) Other Cost (non-Personnel Cost)

1) Methodology

Same as the calculation of required staffs, the other cost like track maintenance cost, electric maintenance cost, etc. except for personnel cost, are calculated by using average unit cost ratio estimated by actual cost result on monorail lines in Japan as a principle ,as shown in Table 9.14. However, traction power cost and utility power cost, which concerning electric power cost, are calculated by using local unit price of electric power consumption.

Table 9.14 Cost Items and Unit Cost Estimation for the Cost but Personnel Cost

Item	Calculating Kind of Cost		Unit Cost
Origin from Japanese Monorail Statistics	Track Maintenance		Per Line-km
	Electric Maintenance		Per Line-km
	Rolling Stock Maintenance	Power Consumption	(Estimated separately)
		Others	Per Number of Rolling Stock
	Train Operation	Traction Power	(Estimated separately)
		Others	Per Number of Drivers
	Station Operation	Utility Power Consumption	(Estimated separately)
		Others	Per Number of Stations
	Administration		Per Number of Staffs
	Others		Ratio for the Total Cost Above

Source: JICA Study Team

2) Unit Cost

Same as the number of staffs, among the monorail lines in Japan, 5 lines, which are straddle type monorail and provide urban transport, are selected and their operation performance data of 2010 are analyzed (Table 9.15). Same as the number of staffs' estimation, unit cost of Tokyo monorail, of which transport volume and capacity is similar to, is adopted. However, regarding the track and electric maintenance cost, those of Osaka monorail are adopted, because Tokyo monorail is pretty old line. Regarding the administration cost, that of Osaka monorail is adopted also because that of Tokyo monorail shows abnormality. In addition the traction power cost and utility power cost in stations are estimated by examining local unit price.

Table 9.15 Unit Cost Actual in Monorail Lines in Japan

Item	Kind of Cost	Unit	Formula	Tokyo	Tama	Osaka	Kita-Kyushu	Okinawa	Remarks
Cost	Track Maintenance		A	743,512	74,767	334,577	18,420	94,338	
	Electric Maintenance		B	244,834	368,774	148,720	134,471	144,475	
(1000 ¥	Rolling Stock Maintenance		C	533,568	758,467	375,168	177,104	134,562	
/year)	(Power Consumption)		C1	6,449	142,264	0	495	4,605	
	(Others)		C2	527,119	616,203	375,168	176,609	129,957	
	Train Operation		D	577,142	125,157	332,817	87,960	127,186	
	(Traction Power)		D1	547,340	77,318	317,609	87,960	115,144	
	(Others)		D2	29,802	47,839	15,208	0	12,042	
	Station Operation		E	766,395	446,488	1,026,858	51,998	95,427	
	(Power Consumption)		E1	218,936					
	(Others)		E2	547,459					
	Administration		F	1,633,631	85,296	327,783	153,809	40,400	
	Sub-Total		G=A～F	4,499,082	1,858,949	2,545,923	623,762	636,388	
	Others		H	267,089	54,898	43,164	1,735	36,298	
	Total		**J=G+H**	**4,766,171**	**1,913,847**	**2,589,087**	**625,497**	**672,686**	
Amount	Line-km	km	a	17.8	16.0	28.0	8.8	12.9	
for Cost	Number of Rolling Stock	Cars	b	120	64	84	40	24	
	Car-km (Year Total)	1000km/year	c	19,929	5,390	9,136	2,667	2,094	
	Number of Drivers	Persons	d	84	53	62	22	35	
	Number of Staffs	Persons	e	331	164	175	131	194	
	Number of Stations (Total)	Stations	f	10	19	18	13	15	
	Number of Stations (Underground)	Stations	g	4					
	Number of Stations (Estimate)	Stations	h=f+g/2	12					
Unit Cost	Track Maintenance	1000JPY/Line-km	j=A/a	41,770	4,673	11,949	2,093	7,313	Selected Osaka *1
	Electric Maintenance	1000JPY/Line-km	k=B/a	13,755	23,048	5,311	15,281	11,200	Selected Osaka *1
	Rolling Stock Maintenance								
	(Power Consumption)	1000JPY/Cars	m1=C1/b	54	2,223	0	12	192	Estimated separately *2
	(Others)	1000JPY/Cars	m2=C2/b	4,393	9,628	4,466	4,415	5,415	
	Train Operation								
	(Traction Power)	JPY/Car-km	n1=D1/c	27.5	14.3	34.8	33.0	55.0	Estimated separately *2
	(Others)	1000JPY/Drivers	n2=D2/d	355	903	245	0	344	
	Station Operation								
	(Utility Power)	1000JPY/Stations (Estimate)	p1=E1/h	18,245					Estimated separately *2
	(Others)	1000JPY/Stations (Estimate)	p2=E2/h	45,622					
	Administration	1000JPY/Staffs	q=F/e	4,935	520	1,873	1,174	208	Selected Osaka *1
	Others	% for Sub-Total	r=H/G	5.94%	2.95%	1.70%	0.28%	5.70%	

(Note) Actual records of Tokyo Monorail are selected as the unit number for estimating the number of personnel in Line 3, because its train operation frequency, number of passengers, distance between stations and commercial speed are similar to Line 3 among 5 sumples.
*1 However, concerning track and electric maintenance staff, actual records of Osaka Monorail are selected bcause Tokyo Monorail has been operating for almost 50 years so its track and electric facilities are old.
Concerning administration cost, actual record of Osaka Monorail is also selected considering total balance of whole costs.
*2 Three cost items concerning electric power consumption are estimated separately.

Source: JICA Study Team

3) Estimation of Cost

a) Base cost from actual operation result in Japan (Before revising Outsourcing Personnel Cost)

Average cost estimation based on the actual operation result in Japan is shown in Table 9.16. O&M cost, which is measured in annual term of 2010 price, is estimated at about USD 36 million, being equivalent to about JPY 3.6 billion at the inauguration year 2020. In the final year of simulation 2050, about USD 42 million, being equivalent to JPY 4.2 billion. O&M cost will increase by 17% during 30 years.

Table 9.16 Estimated O&M Cost (Before revising Outsourcing Personnel Cost)

Item		Kind of Cost	Unit	Formula	2020	2025	2030	2035	2040	2050
Cost・Unit Cost (USD)	Cost	Track Maintenance	1000USD/year	A=a×j	3,092	3,092	3,092	3,092	3,092	3,092
		Electric Maintenance	〃	B=b×j	1,374	1,374	1,374	1,374	1,374	1,374
		Rolling Stock Maintenance	〃	C=c×k	6,874	7,667	7,931	8,196	8,196	8,460
		Train Operation (not include Traction Power)	〃	D=d×n	320	320	338	338	338	363
		Station Operation (not include Utility Power)	〃	E=e×q	5,034	6,406	6,406	6,406	6,406	6,406
		Administration	〃	F=f×p	6,688	7,496	7,665	7,702	7,702	7,909
		Electric Power Consumption	〃	G=g*r	10,729	11,289	11,716	11,757	11,757	12,340
		Sub-Total	〃	Z=A～G	34,111	37,645	38,523	38,866	38,866	39,945
		Others	〃	H=Z×h	2,026	2,236	2,288	2,309	2,309	2,373
		Total	**1000USD/year**		**36,137**	**39,881**	**40,811**	**41,175**	**41,175**	**42,318**
	Unit Cost	Track Maintenance	1000USD/Line-km	a	119.85	119.85	119.85	119.85	119.85	119.85
		Electric Maintenance	1000USD/Line-km	b	53.27	53.27	53.27	53.27	53.27	53.27
		Rolling Stock Maintenance	1000USD/Cars	c	44.06	44.06	44.06	44.06	44.06	44.06
		Train Operation (not include Traction Power)	1000USD/Drivers	d	3.56	3.56	3.56	3.56	3.56	3.56
		Station Operation (not include Utility Power)	1000USD/Stations	e	457.59	457.59	457.59	457.59	457.59	457.59
		Administration	1000USD/Staffs	f	18.79	18.79	18.79	18.79	18.79	18.79
		Electric Power Consumption	USD/kWh	g	0.16	0.16	0.16	0.16	0.16	0.16
		Others	% for Sub-Total	h	5.94%	5.94%	5.94%	5.94%	5.94%	5.94%
Cost・Unit Cost (JPY)	Cost	Track Maintenance	1000JPY/year	A=a×j	308,284	308,284	308,284	308,284	308,284	308,284
		Electric Maintenance	〃	B=b×j	137,024	137,024	137,024	137,024	137,024	137,024
		Rolling Stock Maintenance	〃	C=c×k	685,308	764,382	790,740	817,098	817,098	843,456
		Train Operation (not include Traction Power)	〃	D=d×n	31,950	31,950	33,725	33,725	33,725	36,210
		Station Operation (not include Utility Power)	〃	E=e×q	501,842	638,708	638,708	638,708	638,708	638,708
		Administration	〃	F=f×p	666,788	747,327	764,184	767,930	767,930	788,533
		Electric Power Consumption	〃	G=g*r	1,069,656	1,125,491	1,168,091	1,172,201	1,172,201	1,230,319
		Sub-Total	〃	Z=A～G	3,400,852	3,753,166	3,840,756	3,874,970	3,874,970	3,982,534
		Others	〃	H=Z×h	202,011	222,938	228,141	230,173	230,173	236,563
		Total	**1000JPY/year**		**3,602,863**	**3,976,104**	**4,068,897**	**4,105,143**	**4,105,143**	**4,219,096**
	Unit Cost	Track Maintenance	1000JPY/Line-km	a	11,949	11,949	11,949	11,949	11,949	11,949
		Electric Maintenance	1000JPY/Line-km	b	5,311	5,311	5,311	5,311	5,311	5,311
		Rolling Stock Maintenance	1000JPY/Cars	c	4,393	4,393	4,393	4,393	4,393	4,393
		Train Operation (not include Traction Power)	1000JPY/Drivers	d	355	355	355	355	355	355
		Station Operation (not include Utility Power)	1000JPY/Stations	e	45,622	45,622	45,622	45,622	45,622	45,622
		Administration	1000JPY/Staffs	f	1,873	1,873	1,873	1,873	1,873	1,873
		Electric Power Consumption	JPY/kWh	g	15.95	15.95	15.95	15.95	15.95	15.95
		Others	% for Sub-Total	h	5.94%	5.94%	5.94%	5.94%	5.94%	5.94%

Item	Kind of Amount	Unit	Formula	2020	2025	2030	2035	2040	2050
Amount for Cost	Line-km	km	j	25.80	25.80	25.80	25.80	25.80	25.80
	Number of Rolling Stock	Cars	k	156	174	180	186	186	192
	Car-km (Year Total)	1000km/year	m	21,210	21,284	22,393	22,500	22,500	24,013
	Number of Drivers	Persons	n	90	90	95	95	95	102
	Number of Staffs	Persons	p	356	399	408	410	410	421
	Number of Stations	Stations	q	11	14	14	14	14	14
Electric Power Consumption	Traction Power	1000kWh/year	r1	51,074	51,252	53,922	54,180	54,180	57,823
	Utility Power	1000kWh/year	r2	15,981	19,303	19,303	19,303	19,303	19,303
	Total	1000kWh/year	r=r1+r2	67,055	70,555	73,225	73,483	73,483	77,126

（Note）1.Each year's price is expressed in base year cost (2010).
2.Unit cost of electric power consumption is estimated by refering to the report on O&M cost update of Line1(August 2012) .

Source: JICA Study Team

b) O&M cost (Revised Outsourcing Personnel Cost)

Outsourcing personnel costs are contained in some cost items at some rating among the Japanese actual record base costs estimated in paragraph-a. In Panama and Japan, since a unit personnel price had a difference, outsourcing personnel cost is revised in consideration of this difference.

The revised result is shown in Table 9.17. Revised O&M cost, which is measured in annual term of 2010 price, is estimated at about USD 31 million, being equivalent to about JPY 3.1 billion at the inauguration year 2020. In the final year of simulation 2050, about USD 37 million, being equivalent to JPY 3.7 billion. Revised O&M cost is about 13% lower than the cost before revising.

Table 9.17 Revised O&M Cost

Item		Kind of Cost	Unit	Revised Outsourcing Personnel Cost	2020	2025	2030	2035	2040	2050
Cost (USD)	Personnel Cost	Direct Cost	1000USD/year		5,242	5,815	5,954	5,990	5,990	6,158
		Outsourcing Cost	〃		1,623	1,805	1,832	1,858	1,858	1,885
		Sub-Total	**1000USD/year**		**6,865**	**7,621**	**7,786**	**7,849**	**7,849**	**8,043**
	non-Personnel Cost	Track Maintenance	1000USD/year	Yes	1,546	1,546	1,546	1,546	1,546	1,546
		Electric Maintenance	〃	Yes	687	687	687	687	687	687
		Rolling Stock Maintenance	〃	Yes	4,124	4,600	4,759	4,917	4,917	5,076
		Train Operation (not include Traction	〃	No	320	320	338	338	338	363
		Station Operation (not include Utility Power)	〃	Yes	3,523	4,484	4,484	4,484	4,484	4,484
		Administration	〃	No	6,688	7,496	7,665	7,702	7,702	7,909
		Electric Power Consumption	〃	No	10,729	11,289	11,716	11,757	11,757	12,340
		Sub-Total	〃		27,618	30,423	31,196	31,433	31,433	32,406
		Others	〃	No	2,026	2,236	2,288	2,309	2,309	2,373
		Sub-Total	**1000USD/year**		**29,644**	**32,659**	**33,484**	**33,742**	**33,742**	**34,779**
	Total		**1000USD/year**		**36,509**	**40,279**	**41,270**	**41,590**	**41,590**	**42,822**
Cost (JPY)	Personnel Cost	Direct Cost	1000JPY/year		522,588	579,775	593,654	597,243	597,243	613,992
		Outsourcing Cost	〃		161,832	180,005	182,641	185,276	185,276	187,912
		Sub-Total	**1000JPY/year**		**684,420**	**759,780**	**776,294**	**782,519**	**782,519**	**801,905**
	non-Personnel Cost	Track Maintenance	1000JPY/year	Yes	154,142	154,142	154,142	154,142	154,142	154,142
		Electric Maintenance	〃	Yes	68,512	68,512	68,512	68,512	68,512	68,512
		Rolling Stock Maintenance	〃	Yes	411,185	458,629	474,444	490,259	490,259	506,074
		Train Operation (not include Traction	〃	No	31,950	31,950	33,725	33,725	33,725	36,210
		Station Operation (not include Utility Power)	〃	Yes	351,289	447,096	447,096	447,096	447,096	447,096
		Administration	〃	No	666,788	747,327	764,184	767,930	767,930	788,533
		Electric Power Consumption	〃	No	1,069,656	1,125,491	1,168,091	1,172,201	1,172,201	1,230,319
		Sub-Total	〃		2,753,522	3,033,147	3,110,193	3,133,864	3,133,864	3,230,885
		Others	〃	No	202,011	222,938	228,141	230,173	230,173	236,563
		Sub-Total	**1000JPY/year**		**2,955,533**	**3,256,085**	**3,338,334**	**3,364,037**	**3,364,037**	**3,467,448**
	Total		**1000JPY/year**		**3,639,953**	**4,015,865**	**4,114,628**	**4,146,557**	**4,146,557**	**4,269,352**

Item		Kind of Cost	Ratio1 *2	Ratio2 *2	2020	2025	2030	2035	2040	2050
Revised Outsourcing Personnel Cost	USD (1000USD/year)	Track Maintenance	50%	25%	387	387	387	387	387	387
		Electric Maintenance	50%	25%	172	172	172	172	172	172
		Rolling Stock Maintenance	40%	25%	687	767	793	820	820	846
		Station Operation (not include Utility Power)	30%	25%	378	480	480	480	480	480
		Total			**1,623**	**1,805**	**1,832**	**1,858**	**1,858**	**1,885**
	JPY (1000JPY/year)	Track Maintenance	50%	25%	38,536	38,536	38,536	38,536	38,536	38,536
		Electric Maintenance	50%	25%	17,128	17,128	17,128	17,128	17,128	17,128
		Rolling Stock Maintenance	40%	25%	68,531	76,438	79,074	81,710	81,710	84,346
		Station Operation (not include Utility Power)	30%	25%	37,638	47,903	47,903	47,903	47,903	47,903
		Total			**161,832**	**180,005**	**182,641**	**185,276**	**185,276**	**187,912**

（Note）1.Each year's price is expressed in base year cost (2010).
2.Track , electric, rolling stock maintenance and Station operation cost are revised from the viewpoint of "Outsourcing Personnel Cost".
Revised Cost ＝ Original cost ×Ratio1 × Ratio2
Ratio1 : Estimated rate of outsourcing personnel cost in each cost
Ratio2 : Unit Personnel Cost in Panama/Unit Personnel Cost in Japan

Source: JICA Study Team

(3) Summary of O&M Cost Estimation

Aggregating the result up to here, total O&M cost and the number of staffs are shown in Table 9.18 and Figure 9.13. Total O&M cost, which is measured in annual term of 2010 price, is estimated at about USD 37 million, being equivalent to about JPY 3.6 billion at the inauguration year 2020. In the final year of simulation 2050, about USD 43 million, being equivalent to JPY 4.3 billion. Total O&M cost will increase by 17% during 30 years.

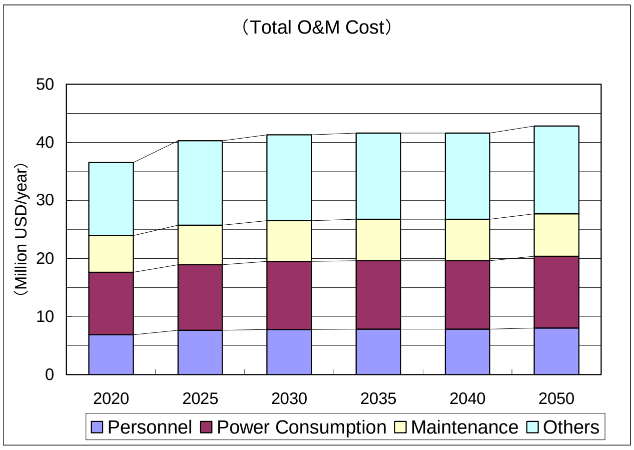
Table 9.18 Summary of Total O&M Cost

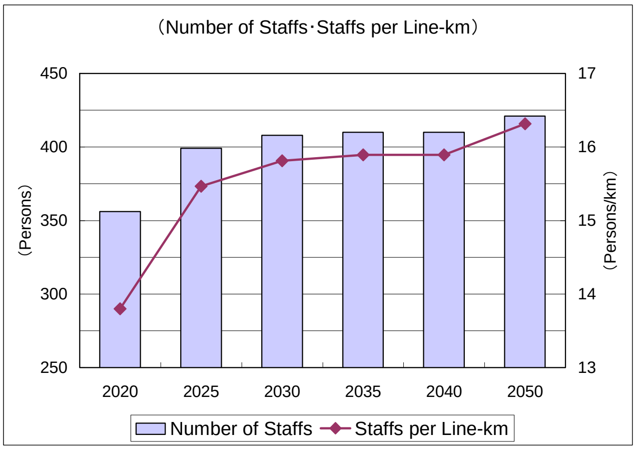
Item		Kind of Cost	Details	2020	2025	2030	2035	2040	2050
Cost (USD)	Base Year Price (1000USD/year)	Personnel	Direct, Outsourcing	6,865	7,621	7,786	7,849	7,849	8,043
		Power Consumption	Traction Power, Utility Power	10,729	11,289	11,716	11,757	11,757	12,340
		Maintenance	Track, Electric, Rolling stock	6,357	6,833	6,992	7,151	7,151	7,309
		Others	Train Operation, Station Operation, Administration,	12,558	14,537	14,776	14,834	14,834	15,129
		Total		**36,509**	**40,279**	**41,270**	**41,590**	**41,590**	**42,822**
	Inflated Price (1000USD/year)	Personnel	Direct, Outsourcing	9,316	12,047	14,339	16,837	19,614	27,276
		Power Consumption	Traction Power, Utility Power	14,559	17,845	21,575	25,222	29,381	41,847
		Maintenance	Track, Electric, Rolling stock	7,234	8,294	9,053	9,876	10,535	12,253
		Others	Train Operation, Station Operation, Administration,	14,289	17,644	19,131	20,487	21,854	25,363
		Total		**45,398**	**55,831**	**64,098**	**72,422**	**81,384**	**106,739**
Cost (JPY)	Base Year Price (1000JPY/year)	Personnel	Direct, Outsourcing	684,420	759,780	776,294	782,519	782,519	801,905
		Power Consumption	Traction Power, Utility Power	1,069,656	1,125,491	1,168,091	1,172,201	1,172,201	1,230,319
		Maintenance	Track, Electric, Rolling stock	633,839	681,283	697,098	712,913	712,913	728,728
		Others	Train Operation, Station Operation, Administration,	1,252,038	1,449,311	1,473,145	1,478,924	1,478,924	1,508,401
		Total		**3,639,953**	**4,015,865**	**4,114,628**	**4,146,557**	**4,146,557**	**4,269,352**
	Inflated Price (1000JPY/year)	Personnel	Direct, Outsourcing	928,772	1,201,069	1,429,551	1,678,656	1,955,487	2,719,377
		Power Consumption	Traction Power, Utility Power	1,451,546	1,779,189	2,151,047	2,514,598	2,929,287	4,172,192
		Maintenance	Track, Electric, Rolling stock	721,229	826,931	902,574	984,629	1,050,315	1,221,639
		Others	Train Operation, Station Operation, Administration,	1,424,662	1,759,151	1,907,368	2,042,593	2,178,859	2,528,685
		Total		**4,526,210**	**5,566,341**	**6,390,540**	**7,220,477**	**8,113,949**	**10,641,892**

		2020	2025	2030	2035	2040	2050
Base Year		2010					
Rate of Inflation	Domestic (Applied to Personnel,	3.1%	3.1%	3.1%	3.1%	3.1%	3.1%
(Each Year)	Imported (Applied to Maintenance, Others)	1.3%	1.3%	1.3%	1.3%	1.3%	1.3%
Rate of Inflation	Domestic (Applied to Personnel,	1.3570	1.5808	1.8415	2.1452	2.4990	3.3911
(Calculation Year/Base Year)	Imported (Applied to Maintenance, Others)	1.1379	1.2138	1.2948	1.3811	1.4733	1.6764

(Note) Base year of costs are set to 2010 by adjusting Japanese actual record year.

Source: JICA Study Team





（Note）Each year's price is expressed in base year cost (2010).

Source: JICA Study Team

Figure 9.13 Total O&M Cost and Number of Staffs)

Chapter 10 Comparison Study on Bridge Planning

10.1 Screening of Main Bridge Type for 4th Panama Canal Bridge

10.1.1 Summary

(1) Objective

The Pre-F/S on the 4th Panama Canal Bridge Construction Project was conducted by ACP based on the Composite Cable-stayed Bridge; however, a comparison study to select the main bridge type for the 4th Panama Canal Bridge was not conducted in that study.

Therefore, a comparison study was conducted in this Study applying the same bridge planning conditions as in the Pre-F/S to screen the main bridge types for the 4th Panama Canal Bridge. Two alternative main bridge types were selected in this screening and the optimum main bridge type would be selected by final comparison study after completion of preliminary design (see Section 16).

(2) Preconditions

This screening was conducted using the same conditions of bridge planning as in the Pre-F/S (Concept Design Report (January, 2013)).

This screening was conducted for the following 2 cases in accordance with the TOR signed between GOP and GOJ on December 6, 2013.

- Not Use the Channel in Erection Works
- Use the Channel in Erection Works

Preconditions of the bridge plan are shown in Table 10.1.

Table 10.1 Preconditions of Bridge Plan

No.	Item		Preconditions	
			Not Use Channel	Use Channel
1	Road Width	Total Width	49.3m	
2	Navigation	Vertical Clearance	75m	
3	Clearance	Horizontal Clearance	300m	
4	Road Alignment		Follow Pre-F/S	
5	Number of Road Layers		1 Layer	
6	Center Span Length		540m	
7	Side Span Length		110m or 160m (see Section 10.1.1(3))	
8	Erection Condition		Not use channel in erection works	Use channel in erection works

Source: JICA Study Team

(3) Selection of Alternative Main Bridge Type

Referring to precedents, the following alternatives were selected based on the applicable span length and the maximum span length.

- Continuous Truss Bridge (Bridge Length: 760m, Span Arrangement: 110m+540m+110m)
- Suspension Bridge (Bridge Length: 860m, Span Arrangement: 160m+540m+160m)
- Solid Rib Arch Bridge (Bridge Length: 760m, Span Arrangement: 110m+540m+110m)
- Composite Cable-stayed Bridge (Original (Pre-F/S)):
  (Bridge Length: 860m*, Span Arrangement: 160m+540m+160m)

*: In the Pre-F/S, the bridge length is 1,040m (250m+540m+250m); however, this selection of span length is optimal for steel cable-stayed, but not optimal for composite cable-stayed bridge. Since the optimum ratio between the side span and the center span stands at 0.3 to 1.0, a side span length of 160m was adopted in this screening.

(4) Screening Method

In this screening, a comparative study was conducted under the following conditions.

- The bridge length of each alternative type is different; therefore, the construction cost of each alternative type was estimated and compared for the same total bridge length of 860m which is the longest among all alternative types.
- Construction costs were assessed absolutely and other items were compared relatively based on the established evaluation criteria.

(5) Evaluation Items and Weighting

The evaluation items and weighting were decided through discussion with SMP, ACP and JICA and it was evaluated on the basis of 100 points. As for the affection to the environment, it was not included in the evaluation items by reason of no difference among the alternative main bridge types.

Evaluation items and weighting are shown in Table 10.2.

Table 10.2 Evaluation Items and Weighting

No.	Item	Weight (Points)	Evaluation Method	Evaluation Point
1	Structure	25	Relative Evaluation	Safety for channel and airspace, Stability against storm and earthquake
2	Constructability	13		Safety risk at construction, Construction duration, Availability of local materials, Construction yard required
3	Maintainability	15		Work volume, Workability, Availability of procurement for maintenance works
4	Landscaping	14		Harmony with the Bridge of the Americas and surroundings, Landmark, Originality, Architectural stability, View from deck surface
5	Cost	33	Absolute Evaluation	Initial construction cost and maintenance cost (100 years)
Total		100		

Source: JICA Study Team

(6) Evaluation Results

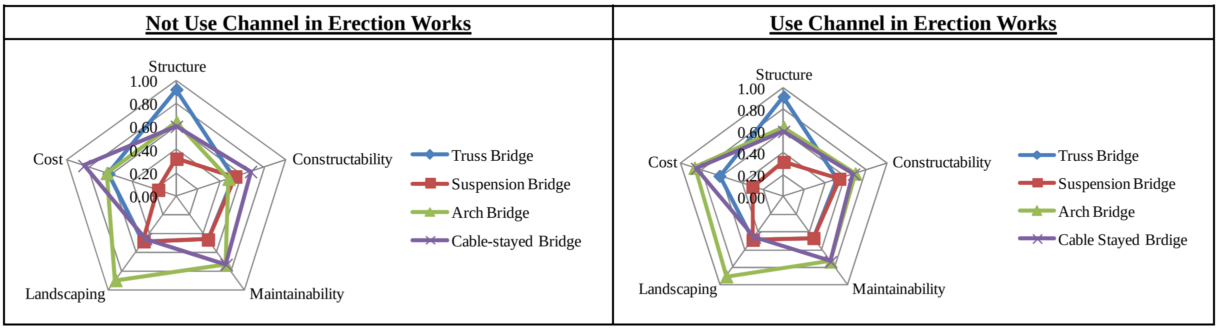
In case the channel is not used in the erection works, the total score of the cable-stayed bridge (69.08 points) exceeded that of the arch bridge (66.80 points) by a narrow margin. Compared to the arch bridge, the cable-stayed bridge is disadvantageous in landscaping; however, it has advantages in constructability and cost. Therefore, in the case of not using the channel in the erection works, the cable-stayed bridge is evaluated as the optimum bridge type.

In the case of using the channel in the erection works, the constructability and cost of the arch bridge are improved and exceed those of the cable-stayed bridge. However, since the arch bridge does not have towers, the degree of airspace interference is lower. In addition, the arch bridge harmonizes with the exterior view of the existing Bridge of the Americas. This feature improves landscaping of the arch bridge. Therefore, in the case of using the channel in the erection works, the arch bridge is the optimum bridge type.

Table 10.3 Evaluation Results

No.	Evaluation Item	Weight (Points)	Not Use Channel in Erection Works				Use Channel in Erection Works			
			Truss Bridge	Suspension Bridge	Arch Bridge	Cable-stayed Bridge	Truss Bridge	Suspension Bridge	Arch Bridge	Cable-stayed Bridge
			Continuous Truss		Solid Rib	Composite	Continuous Truss		Solid Rib	Composite
1	Structure	25	23.00	8.00	16.00	15.00	23.00	8.00	16.00	15.00
2	Constructability	13	6.80	7.00	6.20	8.80	6.80	7.00	9.00	8.80
3	Maintainability	15	7.00	7.00	11.00	11.00	7.00	7.00	11.00	11.00
4	Landscaping	14	6.80	6.80	12.60	6.40	6.80	6.80	12.60	6.40
5	Cost	33	20.50	5.50	21.00	27.88	20.50	10.00	28.50	27.88
Total		**100**	**64.10**	**34.30**	**66.80**	**69.08**	**64.10**	**38.80**	**77.10**	**69.08**
Ranking			**3rd**	**4th**	**2nd**	**1st**	**3rd**	**4th**	**1st**	**2nd**

Source: JICA Study Team



Source: JICA Study Team

Figure 10.1 Radar Chart (Evaluation Results)

(7) Conclusion

The arch bridge and the cable-stayed bridge were selected as the appropriate types for the main bridge in this screening. In the next step, a detailed comparison study will be conducted based on the preliminary design results of the arch bridge and the cable-stayed bridge and the optimum main bridge type will be selected. The preliminary design of the cable-stayed bridge was conducted in the Pre-F/S; therefore, the preliminary design of the arch bridge will be conducted in this JICA Study.

10.1.2 Selection of Alternative Main Bridge Type

(1) Preconditions

This screening was conducted under the same conditions of bridge planning as in the Pre-F/S.

This screening was conducted for the following 2 cases in accordance with the TOR signed between GOP and GOJ on December 6, 2013.

- Not Use the Channel in Erection Works
- Use the Channel in Erection Works

Preconditions of the bridge plan are shown in Table 10.4.

Table 10.4 Preconditions of Bridge Plan

No.	Item		Preconditions	
			Not Use Channel	Use Channel
1	Road Width	Total Width	49.3m	
2	Navigation	Vertical Clearance	75m	
3	Clearance	Horizontal Clearance	300m	
4	Road Alignment		Follow Pre-F/S	
5	Number of Road Layer		1 Layer	
6	Center Span Length		540m	
7	Side Span Length		110m or 160m (see Section 10.1.1(3))	
8	Erection Condition		Not use channel in erection works	Use channel in erection works

Source: JICA Study Team

(2) Establishment of Alternative Main Bridge Type

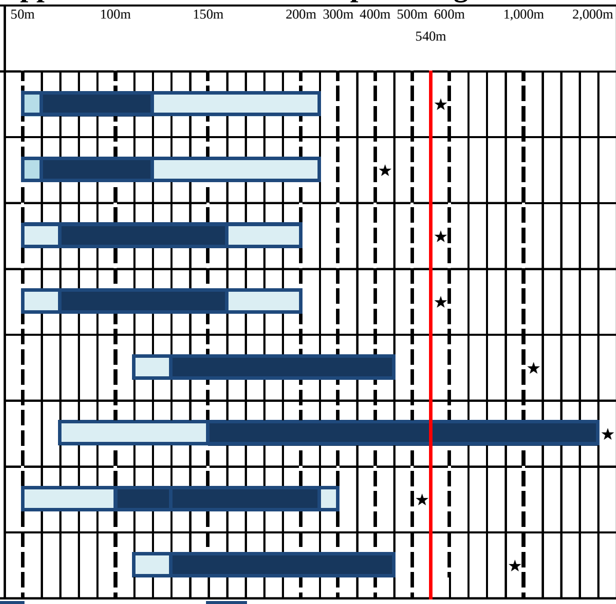
1) Applicable Span Length

Referring to precedents, the bridge types applicable for a center span length of 540m were selected.

As shown in Table 10.5, the bridge type which is applicable for a center span length of 540m is limited to the suspension bridge. However, bridge types which were applied for center span lengths of more than 500m in the past were also selected as alternatives. In addition, since a composite structure (center span: steel girder, side span: PC girder) was also applied for a center span of more than 500m in the past, this structure was also selected as an alternative type.

Applicable and maximum span lengths for each bridge type are shown in Table 10.5.

Table 10.5 Applicable and Maximum Span Lengths for Each Bridge Type



Material	Structure Type		Maximum Span Length of Precedent	Alternative
Steel	Truss	Gerber Truss	Quebec Bridge (Canada, 549m)	
		Continuous Truss	Tokyo Gate Bridge (Japan, 440m)	Selected
	Arch	Braced-rib Arch	Chongqing Chaotianmen Bridge (China 552m)	
		Solid Rib Arch	Shanghai Lupu Bridge (China, 550m)	Selected
	Cable Stayed Bridge		Sutong Bridge (China, 1,088m)	
	Suspension Bridge		Akashi-Kaikyo Bridge (Japan, 1,991m)	Selected
PC	Cable Stayed Bridge		Skarnsund Bridge (Norway, 530m)	
Composite	Cable Stayed Bridge		Tatara Bridge (Japan, 890m)	Selected

★: Maximum Span Length of Precedent   □ : Applicable Span Length   ■ : Optimum Span Length

Source: Design Data Book'11 (2011, Japan Bridge Association),
PC Highway Bridge Planning Manual (Revised) (2009, Japan Prestressed Concrete Contractors Association)

Note

- Steel Cable-stayed Bridge (Tower: Steel and/or Concrete, Main Girder: Steel, Composite 2 main girders)
- PC Cable-stayed Bridge (Tower: Steel and/or Concrete, Main Girder: PC Box Girder)
- Composite Cable-stayed Bridge (Tower: Steel and/or Concrete, Main Girder: Steel Girder+PC Box Girder)

2) Selection of Alternative Type

In the previous Section 10.1.2(2)1), 8 bridge types were selected for the alternative bridge type. Although materials, composition of components and the main structure are different and some bridge types are repeated; the alternative types were further narrowed down based on the following principles:

- Historical progress can be seen.
- Structural weak points are fewer.
- Cost merit is higher.

The selected alternative types and reasons are shown in Table 10.6 in the next page.

Table 10.6 Selected Alternatives and Reasons

No.	Bridge Type	Selected Alternative	Reason for Selection
1	Truss Bridge	Continuous Truss	There are 2 types of truss bridges such as the Gerber girder type and the continuous truss type. The maximum span length for Gerber girder type in the past is 550m, which is in the same range as the 4th Panama Canal Bridge. However, the Gerber type needs Gerber hinges in the center span and they become structural weak points. On the other hand, the maximum span length of a continuous truss in the past is 440m, which is shorter than the other types. However, designing a continuous truss whose center span is 550m is possible using high tensile strength steel. In addition, unlike the Gerber type, this type does not have structural weak points. Therefore, the continuous truss type was selected as an alternative type.
2	Suspension Bridge		Since the suspension bridge has a span that is within the applicable range, it was selected as an alternative type.
3	Arch Bridge	Solid Rib Arch	There are 2 types of arch bridges such as the braced-rib type and the solid rib type. The arch rib of the braced-rib type is a truss structure like the Bridge of the Americas. The arch rib of the solid rib type is a full web box girder. The maximum span length of both types in the past is 550m, which is in the same range as the 4th Panama Canal Bridge. The braced-rib arch gives the impression of an old style bridge like the Bridge of the Americas. On the other hand, the solid rib type gives the impression of an advanced technology because of its slenderness comparing to the braced-rib type. Therefore, the Solid rib type was selected as an alternative type.
4	Cable-stayed Bridge	Composite	There are 3 types of cable-stayed bridges such as the steel cable-stayed bridge with steel girders for all spans, the PC cable-stayed bridge with PC box girders for all spans, and the composite cable-stayed bridge whose center span is steel girder and side span is PC box girder. The maximum span lengths for all types exceed 500m. Initially, cable-stayed bridges were mainly steel cable-stayed bridges or PC cable-stayed bridges. However, recently, composite cable-stayed bridges are adopted in many cases because of its low cost merit. Since this type was adopted by the Pre-F/S, it was selected as an alternative.

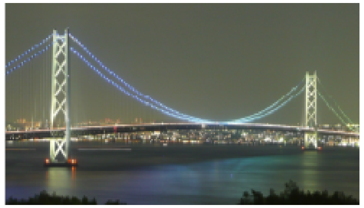
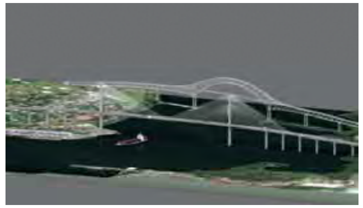
Source: JICA Study Team

10.1.3 Screening Method

(1) Bridge Elements

The bridge elements in the screening are shown in Table 10.7 on the next page.

Table 10.7 Bridge Elements

No.	Item		Alternative 1	Alternative 2	Alternative 3	Original
Precedent			Tokyo Gate Bridge (Tokyo Metropolitan)  Source: Tokyo Metropolitan	Akashi-Kaikyo Bridge (Hyogo Prefecture)  Source: HSBE	Shin-Kizugawa Bridge (Osaka Prefecture)  Source: Osaka City	4th Panama Canal Bridge (Original (Pre-F/S))  Source: Panama Canal Authority
1	Bridge Type		Truss Bridge (Continuous Truss)	Suspension Bridge	Arch Bridge (Solid Rib)	Cable-stayed Bridge (Composite)
2	Total Width		49.3m			
3	Number of Lanes		Road: 6 lanes (3 lanes/direction), MetroLine-3: 2 lanes (1 lane/direction)			
4	Bridge Length		760m	860m	760m	860m
5	Selection of Span Length		110m+540m+110m	160m+540m+160m	110m+540m+110m	160m+540m+160m
6	Deck Type		Concrete Deck			
7	Superstructure Type		Continuous Truss	Suspension Bridge (Cable, Girder, Tower)	Solid Rib Arch (Arch rib, Girder, Cable)	Cable-stayed Bridge (Stay, Girder, Tower)
8	Substructure Type		Pier	Anchorage	Arch abutment, Pier	Pier
9	Foundation Type		Open Caisson			
10	Main Material	Superstructure	Truss: SBHS Deck: Concrete	Main Cable: PWS Girder: Steel Deck: Concrete Tower: Concrete	Arch Rib: SBHS Girder: Steel Cable: Steel Wire	Girder: Steel, PC Stay: PWS Tower: Concrete
11		Substructure	Concrete	Concrete	Arch Abutment: Concrete Pier: Concrete	Concrete
12		Foundation	Concrete			
13	Erection Method	Not Use Channel in Erection Works	Cantilever method (Traveller Crane)	Main Cable: PWS Erection Girder: Lifting and Swinging from a Barge	Erection by Cable Crane (Use inclined Lifting Jointly)	Stay: Erection by Crane Girder: Lifting and Dragging from a Barge PC Girder: Cantilever Erection
		Use Channel in Erection Work	Cantilever Method (Traveller crane)	Main Cable: PWS Erection Girder: Lifting from a Barge	Side Span: Erection by Crane Bents Center Span: Lifting from a Barge	Stay: Erection by Crane Girder： Lifting from a Barge PC Girder： Cantilever Erection

Source: JICA Study Team

(2) Conditions for Comparative Study

In this screening, a comparative study was conducted under the following conditions.

- The bridge length of each alternative type is different; therefore, the construction cost of each alternative type was estimated and compared for the same total bridge length of 860m which is the longest among all alternative types.
- Construction costs were assessed absolutely and other items were compared relatively based on the established evaluation criteria.

(3) Evaluation Items and Weighting

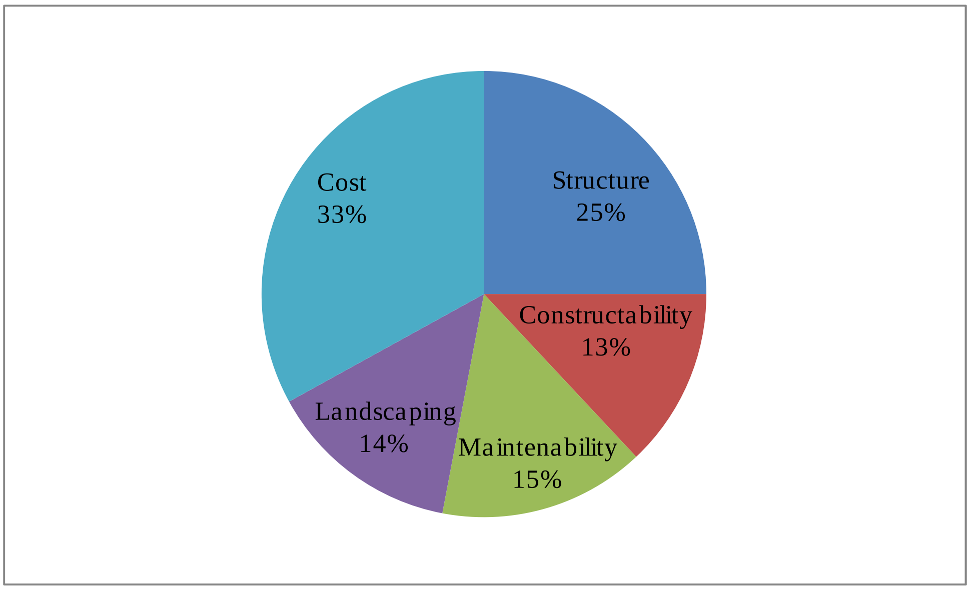
The evaluation items and weighting were decided through discussion with SMP, ACP and JICA and it was evaluated on the basis of 100 points. As for the affection to the environment, it was not included in the evaluation items by reason of no difference among the alternative main bridge types.

Evaluation items and weighting are shown in Table 10.8 and Figure 10.2, respectively.

Table 10.8 Evaluation Items and Weighting

No.	Item	Weight (Points)	Evaluation Method	Evaluation Point
1	Structure	25	Relative Evaluation	Safety for channel and airspace, Stability against storm and earthquake
2	Constructability	13		Safety risk at construction, Construction duration, Availability of local materials, Construction yard required
3	Maintainability	15		Work volume, Workability, Availability of procurement for maintenance works
4	Landscaping	14		Harmony with the Bridge of the Americas and surroundings, Landmark, Originality, Architectural stability, View from deck surface
5	Cost	33	Absolute Evaluation	Initial construction cost and maintenance cost (100 years)
Total		100		

Source: JICA Study Team



Source: JICA Study Team

Figure 10.2 Evaluation Items and Weighting

(4) Evaluation Criteria

Evaluation criteria are shown in Table 10.9 on the next page.

Table 10.9 Evaluation Criteria

Item				Weight (Point)		Evaluation Point	Evaluation Criteria ★★★★★: x1.0	★★★★: x0.8	★★★: x0.6	★★: x0.4	★: x0.2
Evaluation Item	Structure	Safety for Channel and Airspace (Risk for Aircraft and Ship Collision)		10	25	Prioritize the bridge type whose risk of collapse by aircraft and ship collision is low.	Degree of Redundancy: High Airspace Reservation: Not interfere	Between 5 stars and 1 star (Closer to 5 stars than 1 star)	Middle of 5 stars and 1 star	Between 5 stars and 1 star (Closer to 1 star than 5 stars)	Degree of Redundancy: Low Airspace Reservation: Greatly interferes
		Bridge Structure	Wind Resistance Stability	5		Prioritize the bridge type which can minimize to occur vibration and lateral deformation in storm.	Vibration: Hardly occurs Lateral Deformation: Hardly occurs				Vibration: Easily occurs Lateral Deformation: Largely deformes
			Seismic Adequacy	5		Prioritize the bridge type whose acting position of interia force is low and hardly occurs resonance in earthquake.	Acting Position of Interia Force: Low position Natural Period: Long				Acting Position of Interia Force: High position Natural Period: Short
			Rigidity	5		Prioritize the bridge type which has high rigidity of superstructure.	High rigidity				Low rigidity
	Constructability	Safety Risk		4	13	Prioritize the bridge type which can minimize affection to the channel even if dropped components, do not need temporary structures in high place and possesses structural stability during construction.	Affection to the Channel: Small Temporary Structures in High Place: Not require Structural Stability during Construction: Stable				Affection to the Channel: Serious Temporary Structures in High Place: Requires Structural Stability during Construction: Unstable
		Construction Duration		4		Prioritize the bridge type whose construction duration is short.	Short construction duration				Long construction duration
		Availability of Local Materials		3		Prioritize the bridge type which can utilize local materials in construction works.	All materials available				All materials Not available
		Construction yard required		2		Prioritize the bridge type which can minimize size of construction yards and do not require concrete plant at construction site.	Construction Yards: Small Concrete Plant: Not require				Construction Yards: Large Concrete Plant: Requires
	Maintainability	Work Volume (Kind, Number and Exposed Area of Structural Components, Frequency of Maintenance Works)		5	15	Prioritize the bridge type which can minimize nos. of component and frequency subject to inspections and re-painting area.	Components to Inspection: Few Frequency of Inspection: Low Re-painting Area: Small				Components to Inspection: Many Frequency of Inspection: High Re-painting Area: Large
		Workability (Working Space and Accessibility for Maintenance Works)		5		Prioritize the bridge type which can shorten inspection ways in total and ensure enough working spaces.	Inspection Ways: Short Working Spaces: Enough at all places				Inspection Ways: Long Working Spaces: Narrow at all places
		Availability of Procurement for Maintenance Works		5		Prioritize the bridge type which can maintain by local contractors during the operation phase.	Possible all maintenance works				Not possible all maintenance works
	Landscaping	Harmony with the Bridge of the Americas and Surroundings		5	14	Prioritize the bridge type which harmonizes with shape of the Bridge of the Americas and characteristics of surrounding landscape (components of natural landscape).	w/ the Bridge of the Americas: Similar (Shape) w/ Surroundings: Excellent	w/ the Bridge of the Americas: Partially similar (Shape) w/ Surroundings: Good	w/ the Bridge of the Americas: Partially similar (Component) w/ Surroundings: Good	w/ the Bridge of the Americas: Partially similar (Component) w/ Surroundigs: Not harmonize	w/ the Bridge of the Americas: Not similar w/ Surroundings: Not harmonize
		Architectural Features	Landmark	2		Prioritize the bridge type which is different bridge type from other bridges on the Panama Canal and creates peculiar symbolic landscaping around the planned location.	Symbolism: Excellent Peculiar Landscaping: Excellent	Symbolism: Good Peculiar Landscaping: Good	Symbolism: Good Peculiar Landscaping: Slightly Good	Similar bridge type to the other bridges on the Panama Canal	Same bridge type to the other bridges on the Panama Canal
			Originality	3		Prioritize the bridge type which can express the remarkable worldwide design originality with structural rationality by state of the art technologies.	By Structure: Easy By Shape: Easy	By Structure: Easy By Shape: Possible (Inferior to 5 stars)	By Structure: Possible By Shape: Limited	By Structure: Limited By Shape: Limited	By Structure: Not possible By Shape: Not possible
			Architectural Stability	2		Prioritize the bridge type which gives visual sense of stability to horizontal force.	Visual Center of Gravity: Low (Splayed tapered shape)	Visual Center of Gravity: Middle	Visual Center of Gravity: Slightly high	Visual Center of Gravity: High	Visual Center of Gravity: High (Massive in side view)
		View from Deck Surface		2		Prioritize the bridge type whose components do not interfer visibility to the outside of bridge from drivers and monorail users.	Not interfere	From Monorail: Interferes (by thin cables) From Driver: Not interfare	From Monorail: Interferes (by thick cables) From Driver: Not interfare	Interferes both of monorail and driver (by cables)	Interferes both of monorail and driver (by thick components)
	Cost	Construction Cost		25	33	=Weight-2*Weight*(Ratio-1.0)					
		Maintenance Cost (100 years (Present Value))		8							
Total					100						

Source: JICA Study Team

10.1.4 Evaluation Results

(1) Structure

1) Safety for Channel and Airspace

The evaluation was conducted focusing on the risk of a collapse of the structure caused by aircraft collision and the extent of interference with airspace restrictions.

Since the truss bridge has a high degree of statical indeterminacy, the probability of collapse caused by aircraft collision is the lowest among all the alternative types. In addition, the maximum elevation of this type is approximately 100m, which is the lowest among all the alternative types, because it does not have towers. The evaluation of the suspension bridge ranked it the lowest because the breaking of its main cables would cause the collapse of the whole structure. In addition, since it has towers, the maximum elevation is approximately 135m. The degree of statical indeterminacy of the arch bridge is next to that of the cable stayed bridge. This type has no tower. However, the maximum elevation is approximately 120m which is higher than the truss bridge. The degree of statical indeterminacy of the cable-stayed bridge is higher next to that of the truss bridge. However, the tower height is approximately 170m which is the highest among all the alternative types.

Since the center span length of all bridges is 540m and there is no difference among them in ship collision, the evaluation of the shipping lane was not conducted.

The evaluation results (safety for channel and airspace) are shown in Table 10.10.

Table 10.10 Evaluation Results (Safety for Channel and Airspace)

Item	Weight		Truss Bridge	Suspension Bridge	Arch Bridge	Cable-stayed Bridge
Risk of collapse caused by aircraft collision	7	10	5	1	3	4
Extent of interference to airspace reservation	3		4	2	3	1
Evaluation results (weighted average)			4.7	1.3	3.0	3.1
			★★★★★	★	★★★	★★★

Source: JICA Study Team

2) Bridge Structure

a) Wind Resistance Stability

The evaluation was conducted focusing on lateral deformation in storm and the degree of vibration.

Lateral deformation and vibration of the truss bridge are the smallest among all alternative types. Lateral deformation of the suspension bridge is the largest among all alternative types. In addition, winds cause divergent vibration (flutter) to the suspension bridge and may cause the bridge to collapse. Lateral deformation of the arch bridge is larger than the truss bridge. Furthermore, there is a possibility of hanger vibration caused by windows. Lateral deformation of the cable-stayed bridge is in the same extent as the arch bridge. In addition, it has the possibility of stay vibration caused by windows.

The evaluation results (wind resistance stability) are shown in Table 10.11

Table 10.11 Evaluation Results (Wind Resistance Stability)

Item	Weight		Truss Bridge	Suspension Bridge	Arch Bridge	Cable-stayed Bridge
Lateral deformation in storm	2	5	5	1	4	3
Degree of vibration in storm	3		5	1	3	3
Evaluation results (weighted average)			5.0	1.0	3.4	3.0
			★★★★★	★	★★★	★★★

Source: JICA Study Team

b) Seismic Adequacy

The evaluation was carried out focusing on a degree of inertia force moment calculated as a product of the magnitude of inertia force and acting position and natural period which relates to the possibility of resonance.

Although the dead load of the superstructure of the truss bridge is heavy, the inertia moment of this type is small because the acting position is lower. However, since the natural period of this type is short, the possibility of resonance caused by an earthquake is the highest among all alternative types. Although the dead load of the superstructure of the suspension bridge is lighter, the inertia moment of this type is larger because the acting position is higher. However, since the natural period of this type is very long, the possibility of resonance caused by an earthquake is the lowest among all alternative types. The magnitude of inertia force and acting position of the arch bridge is medium degree and the natural period is long. Therefore, the possibility of resonance caused by an earthquake is medium degree.

The evaluation results (seismic adequacy) are shown in Table 10.12.

Table 10.12 Evaluation Results (Seismic Adequacy)

Item	Weight		Truss Bridge	Suspension Bridge	Arch Bridge	Cable-stayed Bridge
Acting position of inertia force moment	2	5	5	2	3	1
Length of natural period	3		1	5	3	4
Evaluation results (weighted average)			2.6	3.8	3.0	2.8
			★★★	★★★★	★★★	★★★

Source: JICA Study Team

c) Rigidity

Deformation is limited based on the service condition. However, considering the service level, a smaller deformation is preferable especially for the monorail system. Therefore, the evaluation was conducted focusing on the rigidity of the superstructure.

Referring to precedents, the rigidity of the superstructure of the truss bridge is the highest and rigidity decreases in the order of arch bridge and cable stayed bridge. The rigidity of the superstructure of the suspension bridge is the lowest.

The evaluation results (rigidity) are shown in Table 10.13.

Table 10.13 Evaluation Results (Rigidity)

Item	Weight		Truss Bridge	Suspension Bridge	Arch Bridge	Cable-stayed Bridge
Rigidity of superstructure	5	5	5	1	4	3
Evaluation results			★★★★★	★	★★★★	★★★

Source: JICA Study Team

(2) Constructability

1) Safety Risk

a) Not Using the Channel in Erection Works

Evaluations were conducted on the height and scale of the temporary structures, the stability of the temporary structures during construction, and the effects on the channel if a component were dropped. .

Since the truss bridge does not have towers, the height of the temporary structures is low and the scale of the temporary structures is small. The stability during construction is inferior because this type is erected by the cantilever method. However, since the components are erected one by one, the impact on the channel from a dropped component is the lowest. As for the suspension bridge, the height of the temporary structure is higher and the scale of the temporary structure is large. However, stability during construction is the highest. The impact on the channel from a dropped stiffening girder is higher. Since the arch bridge requires temporary towers for diagonal hanging, the height of the temporary structure is higher and the scale of the temporary structure is large. In addition, since this type is erected by the cantilever method, the stability during construction is less and the impact on the channel from a dropped stiffening girder is higher. Although the height of the tower of the cable-stayed bridge is the highest, the scale of the temporary structure is small. Stability during construction is less because this type is erected by the cantilever method. Furthermore, the impact on the channel from a dropped stiffening girder is higher. The length of the girder members of the suspension bridge, arch bridge, and cable stayed bridge was assumed to be the same at 10m.

The evaluation results (safety risk) (not using the channel in erection works) are shown in Table 10.14.

Table 10.14 Evaluation Results (Safety Risk) (Not Using Channel in Erection Works)

Item	Weight		Truss Bridge	Suspension Bridge	Arch Bridge	Cable-stayed Bridge
Existence of temporary structures at high place	1	4	5	2	2	1
Size of temporary structures	1		4	3	3	4
Stability under construction	1		1	5	1	2
Affection of the channel at the time of dropping of component	1		4	2	2	2
Evaluation results (weighted average)			3.5	3.0	2.0	2.3
			★★★★	★★★	★★	★★

Source: JICA Study Team

b) Using the Channel in Erection Works

Evaluations were conducted on the height and scale of the temporary structures, the stability of temporary structures during construction, and the effects on the channel if a component were dropped.

Since the truss bridge does not have towers, the height of the temporary structures is low and the scale of temporary structures is small. The stability during construction is inferior because this type is erected by the cantilever method. However, since the components are erected one by one, the effect on the channel from a dropped component is the lowest. As for the suspension bridge, the height of the temporary structure is higher and the scale of the temporary structure is large. However, stability during construction is the highest. The effect on the channel from a dropped stiffening girder is higher. The height of the temporary structures of the arch bridge is next to that of the truss bridge and the scale of the temporary structures is next to that of the arch bridge. In addition, it is erected by a large-block erection method, so the stability during construction is excellent. On the other hand, the arch rib for the large-block erection method is 300m in length and the effect on the channel from a dropped large block would be quite high.

The height of the tower of the cable-stayed bridge is the highest. However, the scale of temporary structure is small. Stability during construction is inferior because this type is erected by the cantilever method. Furthermore, the effect on the channel from a dropped stiffening girder is higher. The length of the girder members of the suspension bridge and cable-stayed bridge was assumed to be 10m.

The evaluation results (safety risk) (using the channel in erection works) are shown in Table 10.15.

Table 10.15 Evaluation Results (Safety Risk) (Use Channel in Erection Works)

Item	Weight		Truss Bridge	Suspension Bridge	Arch Bridge	Cable-stayed Bridge
Existence of temporary structures at high place	1	4	5	2	4	1
Size of temporary structure	1		4	3	4	4
Stability under construction	1		1	5	4	2
Affection of the channel at the time of dropping of component	1		4	1	1	2
Evaluation results (weighted average)			3.5	3.0	3.3	2.3
			★★★★	★★★	★★★	★★

Source: JICA Study Team

2) Construction Duration

a) Not Using the Channel in Erection Works

Since construction duration affects the time of opening to traffic and the project cost, an evaluation was conducted focusing on the construction duration.

Referring to precedents, the construction duration of a cable-stayed bridge is approximately 4 years and is the shortest. Secondly, that of suspension bridge and arch bridge is approximately 6 years. The construction duration of a truss bridge is approximately 8 years and is the longest.

The evaluation results (construction duration) (not using the channel in erection works) are shown in Table 10.16.

Table 10.16 Evaluation Results (Construction Duration) (Not Using the Channel in Erection Works)

Item	Weight		Truss Bridge	Suspension Bridge	Arch Bridge	Cable-stayed Bridge
Construction duration	4	4	1	2	2	5
Evaluation results			★	★★	★★	★★★★★

Source: JICA Study Team

b) Using the Channel in Erection Works

Since the construction duration affects the time of opening to traffic and the project cost, an evaluation was conducted focusing on the construction duration.

Referring to precedents, the construction duration of the cable-stayed bridge and arch bridge is approximately 4 years and is the shortest. Secondly, that of a suspension bridge is approximately 6 years. The construction duration of a truss bridge is approximately 8 years and is the longest.

The evaluation results (construction duration) (using the channel in erection works) are shown in Table 10.17.

Table 10.17 Evaluation Results (Construction Duration) (Using the Channel in Erection Works)

Item	Weight		Truss Bridge	Suspension Bridge	Arch Bridge	Cable-stayed Bridge
Construction duration	4	4	1	2	5	5
Evaluation results			★	★★	★★★★★	★★★★★

Source: JICA Study Team

3) Availability of Local Materials

In order to consider the availability of material and the economic impact on the project area, an evaluation was conducted focusing on the availability of local materials.

Since substructures and foundations are concrete structures of all types, all the materials are available at the construction area. The span length of the truss bridge significantly exceeds the applicable range of the span length. Therefore, special material such as high tensile strength steel is required for the superstructure. As a result, the proportion of imported material is the highest among all alternative types. As for the superstructure of the suspension bridge, the girder material is ordinary steel. However, since the main cable material needs to be imported, the proportion of imported material is high. As for the superstructure of the arch bridge, the girder material is ordinary steel. However, since the material for the arch rib and corner where stress is concentrating need to be imported, the proportion of imported material is high. As for the superstructure of the cable-stayed bridge, the girder material is ordinary steel. However, since the material for the stay needs to be imported, the proportion of imported material is medium.

The evaluation results (availability of local materials) are shown in Table 10.18.

Table 10.18 Evaluation Results (Availability of Local Materials)

Item	Weight		Truss Bridge	Suspension Bridge	Arch Bridge	Cable-stayed Bridge
Superstructure	2	3	1	2	2	3
Substructure and foundation	1		5	5	5	5
Evaluation results (weighted average)			2.3	3.0	3.0	3.7
			★★	★★★	★★★	★★★★

Source: JICA Study Team

4) Construction Yard

a) Not Using the Channel in Erection Works

The required area for a construction yard and the need for a concrete plant were evaluated.

A concrete plant is necessary for the construction of substructures and deck slab for all bridge types. Therefore, all bridges are evaluated equally on this point.

As for the truss bridge, since each structural component is erected one by one, the construction area required is small. However, since the number of structural components is numerous, it requires a material yard. As for the suspension bridge, arch bridge, and cable stayed bridge, they all need a field preassembling yard. Regarding the material yard for structural components, the suspension bridge and arch bridge require less area because the erection period for the main cable and arch rib does not coincide with the erection period for the stiffening girder. However, the cable-stayed bridge requires a large material yard because the stay cable and stiffening girder are erected simultaneously.

The evaluation results (construction yard) (not using the channel in erection works) are shown in Table 10.19.

Table 10.19 Evaluation Results (Construction Yard) (Not Using the Channel in Erection Works)

Item	Weight		Truss Bridge	Suspension Bridge	Arch Bridge	Cable-stayed Bridge
Required area of construction yard	1.5	2	4	3	3	2
Necessity of concrete plant	0.5		3	3	3	3
Evaluation results (weighted average)			3.8	3.0	3.0	2.3
			★★★★	★★★	★★★	★★

Source: JICA Study Team

b) Using the Channel in Erection Works

The required area for a construction yard and the need for a concrete plant were evaluated.

A concrete plant is necessary for the construction of substructures and deck slab for all bridge types. Therefore, all bridges are evaluated equally on this point.

As for the truss bridge, since each member is erected one by one, the construction area required is the smallest. However, since the number of structural components is numerous, it requires a material yard. As for the suspension bridge and cable stayed bridge, they need a field preassembling yard. Regarding the material yard for structural components, the suspension bridge and arch bridge require less area because the erection period for the main cable and arch rib does not coincide with the erection period for the stiffening girder. However, the cable-stayed bridge requires a large material yard because the stay cable and stiffening girder are erected simultaneously. The arch bridge needs the biggest yard for the large block erection.

The evaluation results (construction yard) (use of channel in erection works) are shown in Table 10.20.

Table 10.20 Evaluation Results (Construction Yard) (Use of Channel in Erection Works)

Item	Weight		Truss Bridge	Suspension Bridge	Arch Bridge	Cable-stayed Bridge
Required area of construction yard	1.5	2	4	3	1	2
Necessity of concrete plant	0.5		3	3	3	3
Evaluation results (weighted average)			3.8	3.0	1.5	2.3
			★★★★	★★★	★★	★★

Source: JICA Study Team

(3) Maintainability

1) Work Volume

In this section, the number of structural components and their exposed area, and the frequency of maintenance works were evaluated.

As for the truss bridge, the number of structural members is the most numerous and the exposed area is the largest among all alternative types. The frequency of maintenance works is the least among all alternatives because special cable materials are not used. As for the suspension bridge, the number of structural components is the second least and the exposed area is second smallest after the cable stayed bridge. However, since the main cable material is very special, the frequency of maintenance works is the highest. As for the arch bridge, the number of structural components is same range as the suspension bridge. However, since it has stiffening girders and arch ribs, the exposed area is medium range. Although it has suspension components, the material of the suspension components is not special. Therefore, the frequency of maintenance is not very much. As for the cable-stayed bridge, the number of structural members is the least and the exposed area is the smallest among all alternative types. The frequency of maintenance works is the second highest after the suspension bridge because of the special materials used for the stay.

The evaluation results (work volume) are shown in Table 10.21.

Table 10.21 Evaluation Results (Work Volume)

Item	Weight		Truss Bridge	Suspension Bridge	Arch Bridge	Cable-stayed Bridge
Number of structural components	2	5	1	4	4	5
Exposed area of structural components	2		1	4	3	5
Frequency of maintenance works	1		5	1	4	2
Evaluation results (weighted average)			1.8	3.4	3.6	4.4
			★★	★★★	★★★★	★★★★

Source: JICA Study Team

2) Workability

The workability of maintenance works was evaluated focusing on the amount of narrow working spaces and the length of maintenance route.

As for the truss bridge, it has many narrow spaces in the whole structure and the maintenance routes are the longest. The suspension bridge has narrow spaces in the horizontal components of the tower, tower saddle, and anchorage. Thus, this type has relatively numerous narrow spaces. The maintenance routes are set in the girder, tower, and main cable. Therefore, the length of maintenance routes is relatively longer.

As for the arch bridge, it has narrow working spaces in the horizontal components and the corner. The number of narrow spaces is minimal. The maintenance routes are set in the girder and arch rib. Therefore, the length of maintenance routes is relatively shorter. As for the cable-stayed bridge, it has narrow working spaces in the horizontal components of the tower. The number of narrow spaces is minimal. The Maintenance routes are set in the girder, tower, and stays. Therefore, the length of maintenance routes is relatively shorter.

The evaluation results (workability) are shown in Table 10.22.

Table 10.22 Evaluation Results (Workability)

Item	Weight		Truss Bridge	Suspension Bridge	Arch Bridge	Cable-stayed Bridge
Amount of narrow working area	3	5	1	3	4	4
Total length of inspection ways	2		1	3	4	4
Evaluation results (weighted average)			1.0	3.0	4.0	4.0
			★	★★★	★★★★	★★★★

Source: JICA Study Team

3) Availability of Procurement

Whether maintenance works can be conducted by local contractors or not was evaluated focusing on the specialty of the maintenance works for each bridge type.

As for the truss bridge, since it is made of steel, local contractors can do the maintenance works. However, since special steel material is used for this bridge, local contractors cannot do the repair works by themselves in case repair is needed. As for the suspension bridge, since the material of the main cable is very special, local contractors cannot do the maintenance works and repair works by themselves. The arch bridge and cable-stayed bridge use cable components. Thus, local contractors cannot do repair works by themselves in case repairs are necessary.

The evaluation results (availability of procurement) are shown in Table 10.23.

Table 10.23 Evaluation Results (Availability of Procurement)

Item	Weight		Truss Bridge	Suspension Bridge	Arch Bridge	Cable-stayed Bridge
Availability of local contractors	5	5	4	1	3	3
Evaluation results			★★★★	★	★★★	★★★

Source: JICA Study Team

(4) Landscaping

1) Harmony with the Bridge of the Americas and Surroundings

Harmony with the Bridge of the Americas

The 4th Panama Canal Bridge can be seen as a double silhouette (where two items are seen within the same vision) with the existing Bridge of the Americas (half through braced-rib arch bridge). From the view point of harmony, the evaluation is better if a bridge type reflects the upward curving shape of the span of the Bridge of the Americas. Thus, the degree of harmony with the Bridge of the Americas was evaluated for each bridge types as follows:

4 points: Upward curving shape of the span (completely similar) [arch bridge]

3 points: Composed by truss (part of the shape is similar) [truss bridge]

2 points: Curved shape, but an inverted arch
(only some of the components are similar) [suspension bridge, cable-stayed bridge]

1 point : Shape formed by a straight line (no similar components)

Harmony with Surroundings

The following are the main landscape elements surroundings the 4th Panama Canal Bridge.

- Open sky
- Expansive water surface (Panama Canal)
- Green vegetation extending from the shore to the distance
- Gently-sloping mountains and hills
- Warehouses at the port
- Gantry cranes standing in a row
- Navigating ships

The main landscape elements are the sky, the surface of the water, and green mountains which occupy a large part of a visual field. It can be expressed as an "open and spacious natural landscape" in which the mountains present a soft skyline. Gantry cranes exist conspicuously in part of the landscape. However, the area in the visual field is not large. The landscape of the port, including gantry cranes, is not the primary landscape compared to the natural landscape. It can be considered that the port landscape shows only complexity. Thus, from the view point of being in harmony with the surroundings, a bridge type's harmony with an "open and spacious natural landscape" was considered and the evaluation was conducted as follows:

4 points: Extension based on a horizontal line and a shape similar to the gently-sloping topography. (harmonized) [arch bridge]

3 points: The shape is based on a horizontal line. However, it is not similar to the topography. (harmonized to some degree) [truss bridge]

2 points: Vertical components obstructing the horizontal lines are conspicuous. However, some parts of the shape have a gentle impression. (minimally harmonized) [suspension bridge]

1 point : Vertical components obstructing the horizontal lines are conspicuous and the shape is composed by straight lines. (not harmonized) [cable-stayed bridge]

Source: JICA Study Team

Figure 10.3 The Existing Bridge of the Americas (Photo)

<u>Evaluation Results</u>

The evaluation results (harmony with the Bridge of the Americas and surroundings) are shown in Table 10.24.

Table 10.24 Evaluation Results (Harmony with the Bridge of the Americas and Surroundings)

Item	Weight		Truss Bridge	Suspension Bridge	Arch Bridge	Cable-stayed Bridge
Harmony with the Bridge of the Americas	3	5	3	2	4	2
Harmony with surroundings	2		3	2	4	1
Evaluation results (weighted average)			3.0	2.0	4.0	1.6
			★★★	★★	★★★★	★★

Source: JICA Study Team

2) Architectural Features

a) Landmark

A landmark is evaluated by locality, symbolism and so forth and relates to a person's recognition of its significance. A landmark needs to have an excellent appearance which represents the local culture (with a difference from another region or country, etc.) and its appearance needs to let people know where they are and what the surroundings are when they see it.

Its presence clearly represents the region itself. "Locality" means a unique shape that contributes to the landscape of the region.

From the view point of symbolism, having a "gate like characteristic" that symbolizes the Pacific entrance to the canal is also part of the evaluation. Whether the shape of the bridge corresponds to shipping activity (ships passing under the bridge) is an evaluation point.

Following is an explanation of the evaluation results:

5 points : It is an excellent local landmark. In addition, the arch shape has an excellent symbolism as a gate [arch bridge]

4 points : The inverted arch shape can be a landmark which represents the region. The symbolism as a gate is less to some degree [suspension bridge]

3 points : The shape composed by straight lines is monotonous; it is difficult to consider it a landmark which represents the region. It has the symbolism as a gate to some degree [Truss bridge]

1 point : This is the same type of bridge that already exists on the canal, it could hardly be recognized as an original landmark. The symbolism of a triangular shape as a gate is lower [cable-stayed bridge]

The evaluation results (landmark) are shown in Table 10.25.

Table 10.25 Evaluation Results (Landmark)

Item	Weight		Truss Bridge	Suspension Bridge	Arch Bridge	Cable-stayed Bridge
Landmark	2	2	3	4	5	1
Evaluation results			★★★	★★★★	★★★★★	★

Source: JICA Study Team

b) Originality

Technology progresses continuously and new technology produces new types. Therefore, the possibility of a new structure based on new technology and a new type based on a rational structure were evaluated for each type.

5 points : A world class state-of-the-art structure and type can be made by using new material [arch bridge]

3 points : New material is applicable. However, there is little opportunity to use new material in the evolution of shape [truss bridge]

2 points : New material is applicable. However, there are few structural components in which new material can be applied. The originality of shape is lower [suspension bridge, cable-stayed bridge]

The evaluation results (originality) are shown in Table 10.26.

Table 10.26 Evaluation Results (Originality)

Item	Weight		Truss Bridge	Suspension Bridge	Arch Bridge	Cable-stayed Bridge
Originality	3	3	3	2	5	2
Evaluation results			★★★	★★	★★★★★	★★

Source: JICA Study Team

c) Architectural Stability

Architectural stability was evaluated focusing on a visual stability against a horizontal force. In case a horizontal force is applied, a shape was evaluated highly when its structural members gave the perception of having resistance to a horizontal force. In addition, if it seemed that heavy items exist in the upper part (for example, tall slender piers or many structural components are seen in the upper part.) from the side view, the center of gravity looks higher and gives an unstable impression. Therefore, such case was evaluated to be low.

5 points: The side view presents a shape spreading downward in all directions. The center of gravity looks lower. Stability is felt [arch bridge]

4 points: The center of gravity looks relatively higher; however, stability is felt [cable-stayed bridge]

3 points: The center of gravity looks relatively higher and a lack of stability is felt [suspension bridge]

1 point : The center of gravity looks the highest. The side view gives a massive and unstable impression [truss bridge]

The evaluation results (architectural features) are shown in Table 10.27.

Table 10.27 Evaluation Results (Architectural Features)

Item	Weight		Truss Bridge	Suspension Bridge	Arch Bridge	Cable-stayed Bridge
Architectural stability	2	2	1	3	5	4
Evaluation results			★	★★★	★★★★★	★★★★

Source: JICA Study Team

3) View from the Deck Surface

The degree of interference with the panoramic view of monorail passengers, pedestrians, and car passengers.

4 points: Thin cables exist outside of the monorail. However, there are no components to the outside of the road. It presents a feeling of openness [arch bridge]

3 points: Although relatively thick cables exist to the outside of the monorail, there are no components to the outside of the road. It presents a feeling of openness [cable-stayed bridge]

2 points: Cables exist to the outside of the monorail and the road. Obstruction of view is felt to some degree [suspension bridge]

1 point : Cables exist to the outside of the monorail and the road. Intense obstruction of view is felt [truss bridge]

The evaluation results (view from the deck surface) are shown in Table 10.28.

Table 10.28 Evaluation Results (View from Deck Surface)

Item	Weight		Truss Bridge	Suspension Bridge	Arch Bridge	Cable-stayed Bridge
View from deck surface	2	2	1	2	4	3
Evaluation results			★	★★	★★★★	★★★

Source: JICA Study Team

(5) Cost

Regarding cost, initial construction cost and maintenance cost (100 years) based on precedents were compared among the bridge types. As for the evaluation points, the following equation was adopted so that a type whose cost to lowest cost ratio is 1.5 would have 0 points.

Points = Scouring Weight - 2*Scouring Weight * (The ratio to the lowest cost-1.0)

Costs were calculated in a following manner.

- Initial cost and maintenance cost were calculated using unit prices in Japan referring to the approximate cost for the preliminary design of the same bridge type in an overseas project.
- As for the initial cost, unit prices in Japan were converted into local currency based on the results of the Pre-F/S and the 3rd Panama Canal Bridge.
- Maintenance costs were established in ratio to initial cost and maintenance cost calculated in reference to projects in Japan.
- As for the ratio between the initial cost and maintenance cost for cable stayed bridges, it was confirmed that the ratio of reference projects in Japan was almost same as the ratio of the 3rd Panama Canal Bridge.
- In order to compare the cost for a bridge length of 860m for all bridge types, the cost of an approach bridge (100m) were added to the truss bridge and arch bridge. The cost was referred to the results of the Pre-F/S.

The scouring weight and discount rate were adjusted to JICA’s policy in the following way:

- Evaluate maintenance cost by present value (discount rate: 4%)
- Apply a scouring weight of 25 points (initial construction cost) and 8 points (maintenance cost) (Initial Construction Cost : Maintenance Cost = 3:1)

The evaluation results (cost) (not using the channel in erection works) and the evaluation results (using the channel in erection works) are shown in Tables 10.29 and 10.30, respectively.

Table 10.29 Evaluation Results (Cost) (Not Using the Channel in Erection Works)

Item	Weight		Truss Bridge	Suspension Bridge	Arch Bridge	Cable-stayed Bridge
Initial construction cost	25	33	20.50 (360Mil.USD) (Ratio=1.09)	5.50 (460Mil.USD) (Ratio=1.39)	13.00 (410Mil.USD) (Ratio=1.24)	25.00 (340Mil.USD) (Ratio=1.00)
Maintenance cost (100 years) (Present value)	8		0.00 (46Mil.USD) (Ratio=1.84)	0.00 (43Mil.USD) (Ratio=1.72)	8.00 (25Mil.USD) (Ratio=1.00)	2.88 (33Mil.USD) (Ratio=1.32)
Evaluation results			20.50	5.50	21.00	27.88

Source: JICA Study Team

Table 10.30 Evaluation Results (Cost) (Using the Channel in Erection Works)

Item	Weight		Truss Bridge	Suspension Bridge	Arch Bridge	Cable-stayed Bridge
Initial construction cost	25	33	20.50 (360Mil.USD) (Ratio=1.09)	10.00 (430Mil.USD) (Ratio=1.30)	20.50 (360Mil.USD) (Ratio=1.09)	25.00 (330Mil.USD) (Ratio=1.00)
Maintenance cost (100 years) (Present value)	8		0.00 (46Mil.USD) (Ratio=1.84)	0.00 (43Mil.USD) (Ratio=1.72)	8.00 (25Mil.USD) (Ratio=1.00)	2.88 (33Mil.USD) (Ratio=1.32)
Evaluation results			20.50	10.00	28.50	27.88

Source: JICA Study Team

10.1.5 Conclusion

(1) Evaluation Results

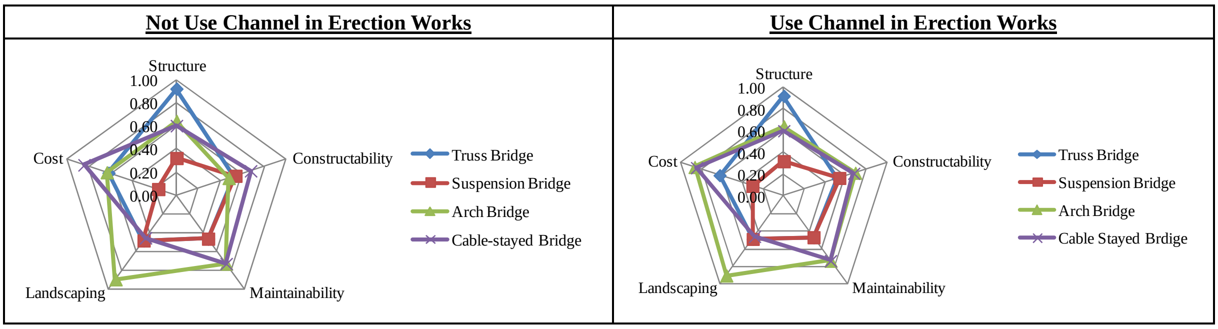
In case the channel is not used in erection works, the total score of the cable-stayed bridge (69.08 points) exceeded that of the arch bridge (66.80 points) by a narrow margin. Compared to the arch bridge, the cable-stayed bridge is disadvantageous in landscaping; however, it has advantages in constructability and cost. Therefore, in the case of not using the channel in erection works, the cable-stayed bridge is evaluated to be the optimum bridge type.

In case of using the channel in erection works, the constructability and cost of the arch bridge are improved and surpass those of the cable-stayed bridge. Furthermore, since the arch bridge does not have towers, the degree of airspace interference is lower. In addition, the arch bridge harmonizes with the exterior view of the existing Bridge of the Americas. This feature improves the landscaping of the arch bridge. Therefore, in the case using the channel in erection works, the arch bridge is the optimum bridge type.

Table 10.31 Evaluation Results

No.	Evaluation Item	Weight (Points)	Not Use Channel in Erection Works				Use Channel in Erection Works			
			Truss Bridge	Suspension Bridge	Arch Bridge	Cable-stayed Bridge	Truss Bridge	Suspension Bridge	Arch Bridge	Cable-stayed Bridge
			Continuous Truss		Solid Rib	Composite	Continuous Truss		Solid Rib	Composite
1	Structure	25	23.00	8.00	16.00	15.00	23.00	8.00	16.00	15.00
2	Constructability	13	6.80	7.00	6.20	8.80	6.80	7.00	9.00	8.80
3	Maintainability	15	7.00	7.00	11.00	11.00	7.00	7.00	11.00	11.00
4	Landscaping	14	6.80	6.80	12.60	6.40	6.80	6.80	12.60	6.40
5	Cost	33	20.50	5.50	21.00	27.88	20.50	10.00	28.50	27.88
Total		**100**	**64.10**	**34.30**	**66.80**	**69.08**	**64.10**	**38.80**	**77.10**	**69.08**
Ranking			**3rd**	**4th**	**2nd**	**1st**	**3rd**	**4th**	**1st**	**2nd**

Source: JICA Study Team



Source: JICA Study Team

Figure 10.4 Radar Chart (Evaluation Results)

(2) Conclusion

The arch bridge and cable-stayed bridge were selected as the appropriate main bridge types in this screening. In the next step, a detailed comparison study will be conducted based on the preliminary design results of the arch bridge and the cable-stayed bridge and the optimum main bridge type will be selected. The preliminary design of the cable-stayed bridge was conducted in the Pre-F/S; therefore, the preliminary design of the arch bridge will be conducted in this JICA Study.

10.2 Study of Platform Plan for 4th Panama Canal Bridge

(1) Objective

In accordance with the study results of Section 5.1 Screening of Main Bridge Type of 4th Panama Canal Bridge, the preliminary design of the arch bridge will be conducted in the JICA Study. However, the 4th Panama Canal Bridge will have 6 lanes of roadway and 2 lanes of Metro Line-3 and the bridge width of more than 50m is required.

Therefore, the optimum platform plan of arch bridge was studied.

(2) Study Items

Single and double-deck plans were selected as alternative platform plans in consideration of the following gradient requirements for the approach sections (see Section 11.4.3(1)1)b)).

- Road: 4%
- Metro Line-3: Max. 6%

The evaluation items were established as follows:

- Road Serviceability
- Structure
- Cost
- Maintainability

(3) Study Results

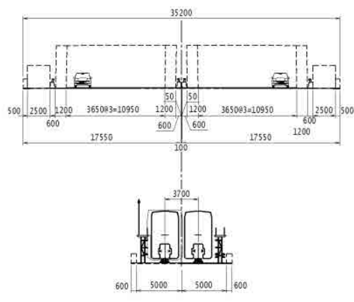
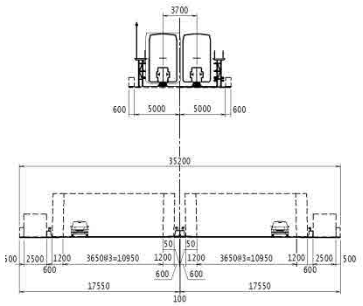
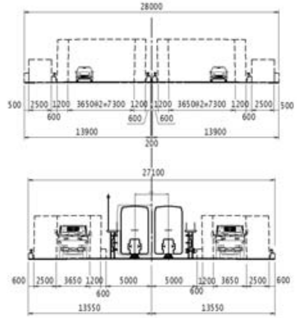
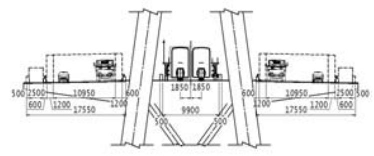
A summary of the study results of platform plan is shown in Table 10.32.

(4) Conclusion

Alternative D (single deck plan) was selected as the optimum platform plan and was applied in the preliminary design of the arch bridge in the JICA Study.

In this Study, the location of Metro Line 3 was in the center of the main bridge, however, its location was revised to the south side (Pacific Ocean side) after this Study because of the relocation of Balboa and Panama Pacifico Stations to the south side in the Metro Line-3 Study. However, this has not affected the results of this study; therefore, a new study was not conducted based on the revised location of Metro Line-3 on the main bridge.

Table 10.32 Summary of Study Results of Platform Plan (Main Bridge of 4th Panama Canal Bridge)

Item		Double Deck			Single Deck
		Alternative A	Alternative B	Alternative C	Alternative D
Platform Plan					
Road Serviceability	Metro Profile	★★★★★: Max. 4%	★★★★★: Max. 6%	★★★★★: Max. 4%	★★★★★: Max. 4%
	Road Profile	★★: Max. more than 5%	★★★★★: Max. 4%	★★★★: Max. 4% (Heavy Vehicle) Max. more than 5% (Small Vehicle)	★★★★★: Max. 4%
	Alignment (Approach)	★★★: Alignment: Simple Independent section: Long	★★★: Alignment: Simple Independent section: Long	★★: Alignment: Complexity Independent section: Long	★★★★★: Alignment: Simple Independent section: Short
	Road Configuration	★★★★★: 3 lanes/direction	★★★★★: 3 lanes/direction	★: 2 lanes+1 lane/direction (separate)	★★★★★: 3 lanes/direction
Structure	Configuration (Stiff. Girder)	★★★★: Well balanced by applying inverted trapezoid	★★★: Too much redundant space on upper layer	★★★★★: No redundant space	★★★: No redundant space but cantilever length≥15m
	Girder Spacing	★★★: Approx. 40m	★★★: Approx. 40m	★★★★: Approx. 30m	★★★★★Approx. 15m
	Wind Resistance	<u>Aerodynamic Stability</u> ★★★★★: Excellent <u>Static Stability</u> ★★★: Average	<u>Aerodynamic Stability</u> ★★★★★: Excellent <u>Static Stability</u> ★★★: Average	<u>Aerodynamic Stability</u> ★★★★★: Excellent <u>Static Stability</u> ★★★: Average	<u>Aerodynamic Stability</u> ★★★★: Good By reason of box shape, inferior to truss structure but superior than cable-stayed bridge <u>Static Stability</u> ★★★★: Good
Initial Construction Cost[1)]		★★: Approx. 45 Bil.JPY (450 Mil.PAB) (Steel Weight: Approx. 47,000tons) (Approach Section: Approx. 800m)	★★: Approx. 45 Bil.JPY (450 Mil.PAB) (Steel Weight: Approx. 47,000tons) (Approach Section: Approx. 800m)	★★★: Approx. 41 Bil.JPY (410 Mil.PAB) (Steel Weight: Approx. 43,000tons) (Approach Section: Approx. 1,600m)	★★★★★: Approx. 36 Bil.JPY (360 Mil.PAB) (Steel Weight: Approx. 38,800tons) (Approach Section: Approx. 800m)
Maintainability		★★★★: Large re-painting area (truss structure)	★★★★ : Large re-painting area (truss structure)	★★★★ : Large re-painting area (truss structure)	★★★★★ : Less painting area (box shape)
Evaluation Results		**<u>Not Acceptable</u>** (Not satisfy the road serviceability) (Max. Gradient (Heavy Vehicle): More than 5%)	**<u>2nd Rank</u>** Satisfy road serviceability but inferior to Alt. D by cost and independent section length	**<u>3rd Rank</u>** Satisfy road serviceability but inferior to Alt. D by cost, alignment, independent section length	**<u>1st Rank</u>** Satisfy road serviceability and superior to other alternatives in cost

1) Estimated by the ratio of steel weight based on the cost data in Section 10.1: Screening of Main Bridge Type of 4th Panama Canal Bridge

Source: JICA Study Team

Chapter 11 Preliminary Road Design

11.1 Summary

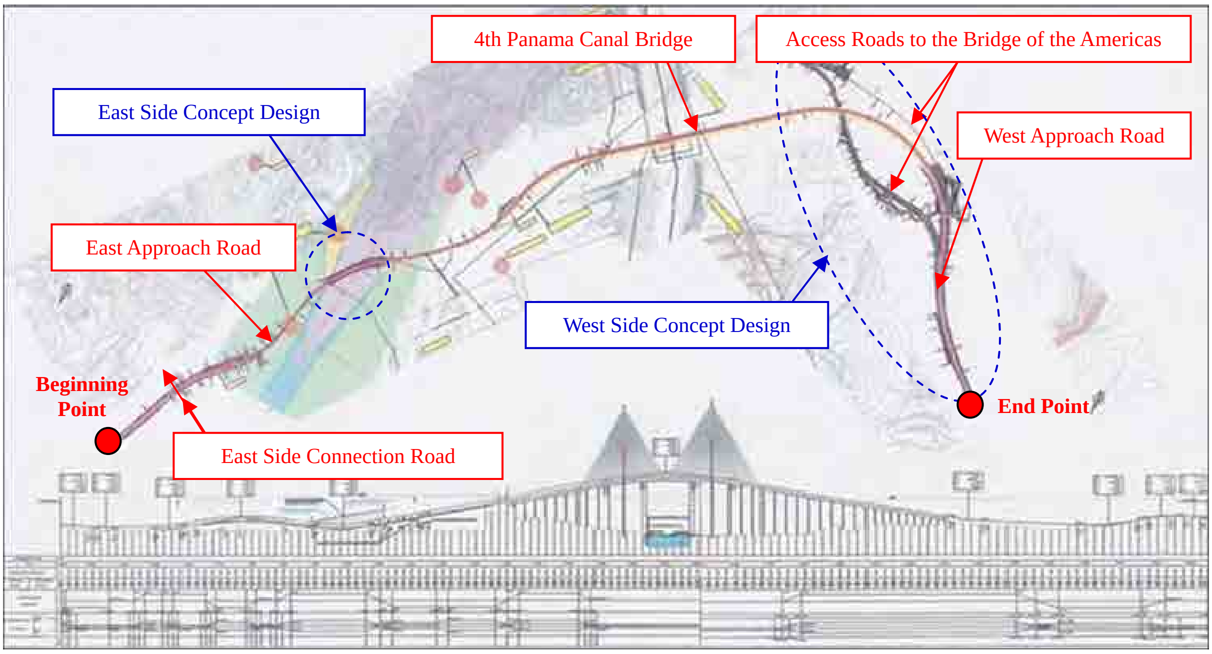
11.1.1 Objective

The objective of the study is to decide on the scope of the project and to estimate the preliminary project cost based on the preliminary designs of the road and ancillary facilities, the preparation of drawings and the calculation of quantities. In addition, the connectivity between the east and west approach roads and the existing roads needs to be ensured in order to fully achieve the Project's effects; therefore, the design, preparation of drawings and calculation of quantities, at concept design level, were also conducted for the connectivity.

11.1.2 Study Items

The contents of the road design study are presented below.

A location map of the designed roads is shown in Figure 11.1.



Source: JICA Study Team based on Pre-F/S (Concept Design Report (January 2013)) (ACP)

Figure 11.1 Location Map of the Design Road

(1) Collection and review of existing materials

- Collection and review of the results of the Pre-F/S and related materials

(2) Preliminary Design

- Adjustment with the Panama City Urban Transportation Line-3 Project in its alignment and structure.
- Preliminary design of the East and West Approach Roads (new construction) of the 4th Panama Canal Bridge
- Preliminary design of the Connection Road on the east side (new construction)
- Preliminary design of the Access Roads to the Bridge of the Americas on the west side (reconstruction)

(3) Concept Design

- Connectivity studies for the connecting roads/ramps between the East/West Approach Roads and the existing road
- Evaluations of Service level of the eastside concept design by carrying out a micro simulation of the eastside connectivity.

11.1.3 Revisions and Proposals based on the Pre-F/S

As a result of the study, the design from the Pre-F/S was improved upon and additional proposals for the design were made as described below.

(1) Preliminary Design

The design speed of the Access Roads was changed from 120km/hr to 100km/hr because the slowing of trucks (approaching the bridge) will create a greater difference in the traveling speeds between trucks and cars. Also, in the section between the beginning point and the merging/diverging nose at the west side of Omar Torrijos roundabout, the design speed was reduced from 100km/hr to 80km/hr due to the short distance of the merging and diverging nose. Road structures were changed from embankment to retaining wall in the earth work section from the Omar Torrijos roundabout to the merging/diverging nose, because constructions must be carried out in a small/limited space beside the Roosevelt Ave.

The results of the preliminary design are shown in Table 11.1.

Table 11.1 Summary of the Results of Preliminary Design

	Approach Road	Connection Road at East Side	Access Road to the Bridge of the Americas
Beginning Point/ End Point (Length)	Beginning Point: Albrook Area Connecting to Corredor Norte End Point: before the Howard Intersection connecting to Panamerican Highway (L=6,720.212m)	Beginning Point: Albrook Area End point: Omar Torrijos Roundabout (L= 1,025.190m) (On Ramp: L=400.200m) (Off Ramp: L=624.990m)	Beginning Point: Howard Intersection End point: Bridge of the Americas (L=3,170.400m) (Inbound: L=1,582.400m) (Outbound: L=1,588.000m)
Road Class	Arterial Road (full access controlled, toll-free operation)	Ramp (connecting with Approach road and main urban road)	Rural Road
Number of Lanes	From Beginning Point to merging/diverging nose at the west side of Omar Torrijos roundabout: 2 way, 4-lane From said nose to the End Point: 2 way, 6-lane	1 way, 2 lanes	1 way, 2 lanes
Design Speed	From Beginning Point to merging/diverging nose at the west side of Omar Torrijos roundabout: 80km/hr From said nose to the End Point: 100km/hr	40km/hr	80km/hr
Road Structure	Earth work (including retaining wall) and Bridge	Earth work and Bridge	Earth work and Bridge

Source: JICA Study Team

(2) Concept Design

Based on the Pre-F/S, additional ramps were studied in order to improve the connectivity between the East/West Access Roads of the 4th Panama Canal Bridge and the existing road. Ramps were planned for connecting to the Omar Torrijos roundabout on the east side. After the study, the removal of the existing flyover was considered.

On the west side of the Canal, additional ramps were planned for connecting the Approach Road with the Access Roads to the Bridge of the Americas.

The results of the concept design are shown in Table 11.2.

Table 11.2 Summary of the Results of Concept Design

Items	East Side Area		West Side Area
	Underpass	Additional Ramps	Additional Ramps
Beginning Point/ End Point (Length)	Omar Torrijos Ave.: L=1,500m F Ramp (on): L=1,520m G Ramp (off): L=1,500m	A Ramp L=500m B Ramp L=650m C Ramp L=350m D Ramp (off) L=350m E Ramp L=350m H Ramp (off) L=200m I Ramp (on) L=350m	X Ramp (U-turn) L=1130m Ramps to the Existing Roads (Y and a to i Ramps)
Road Class	Urban Road/Ramp	Ramp	Ramp/Rural Road
Number of Lanes	Underpass: 2 ways, 2 lanes On/Off Ramp: 1 way, 2 lanes	1 way, 1 or 2 lanes	1 way, 1 or 2 lanes
Design Speed	60km/hr	40km/hr	40km/hr
Road Structure	Earth work (including retaining wall) and Bridge	Earth work (including retaining wall) and Bridge	Earth work and Bridge

Source: JICA Study Team

11.1.4 Conclusion of Preliminary Road Design

(1) Preliminary Design

The Preliminary design was carried out based on the concept design of the Pre-F/S (January, 2013) due to the delayed submission of the draft final report of the Pre-F/S in December, rather than October 2013, as originally planned. In the Draft Final Report (as of November, 2013) of the Pre-F/S, the design speed of the Approach Road was reduced from 120km/hr to 90km/hr in order to keep the stopping sight distance, while its horizontal and vertical alignments were not changed from the concept design report.

In this preliminary design, the design speed of 100km/hr has been applied to the Approach Road because safety requirements, including the stopping sight distance, can be satisfied with this improved design.

(2) Concept Design

The micro-simulation of the Omar Torrijos intersection (Concept Design at the east side) was executed. Based on the results of the analysis by micro-simulation, verifications were made of the service level. This information is presented in 11.5.2 of this Draft Final Report.

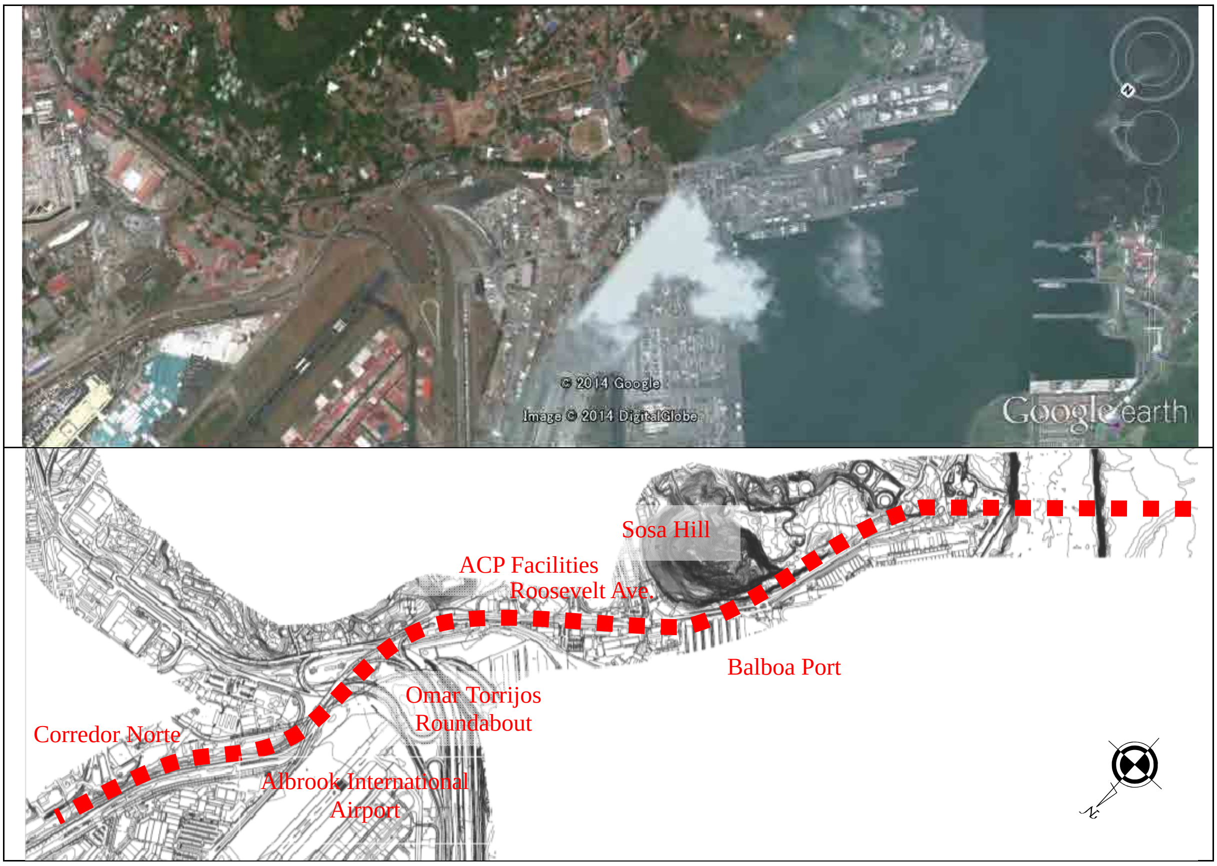
11.2 General Condition of the Route

11.2.1 General condition of the Route

An Approach Road connects to the Corredor Norte at the beginning point and passes over the Omar Torrijos roundabout, the route then runs along the Roosevelt Ave and connects to the 4th Panama Canal Bridge. On the west side, the route runs westward along the Panamerican Highway, and reaches its end point before the intersection with the access road to Panama Pacifico. The total length of this Arterial Road is 6.7km.

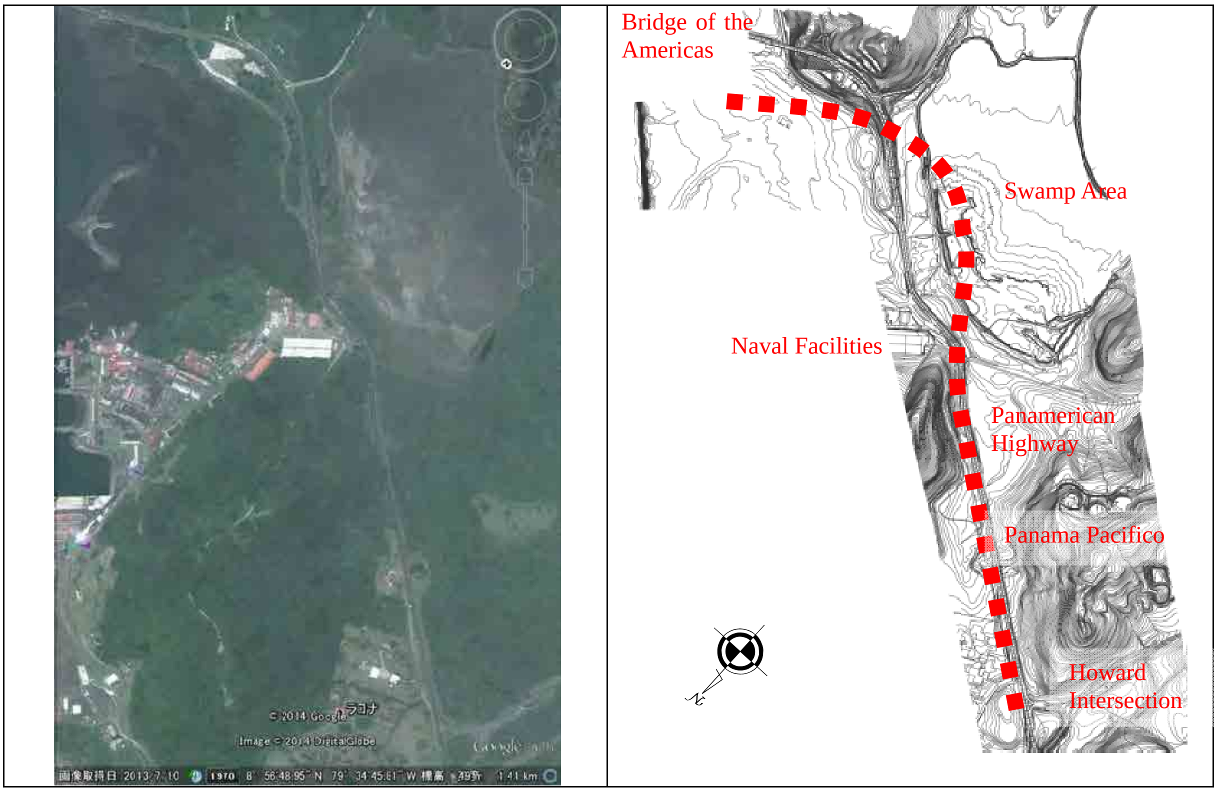
There is a large shopping center (Albrook Mall) and the National Bus Terminal near the starting point. A Metro Line-1 and Metro Line-3 station will be constructed in the vicinity. The Albrook International (Marcos A. Gelabert) Airport is to the north of Omar Torrijos roundabout and its runway is close to the roundabout. There are many ACP facilities on the south side of Roosevelt Ave, and there is an intersection connecting to the Bridge of America to the west. Also, north of Roosevelt Ave are the facilities of Balboa port, and to the south, just before the 4th Panama Canal Bridge, is Sosa Hill.

On the west side of the Canal where the Bridge of the Americas connects to the Panamerican Highway, there is a marshland covered with mangroves. At the endpoint of the route is a hill. The present condition on the east side of 4th Panama Canal Bridge is shown in Figure 11.2, and the west side is shown in Figure 11.3.



Source: Upper/Google Earth, Lower/JICA Study Team

Figure 11.2 Present Condition on the East Side of 4th Panama Canal Bridge



Source: Left/ Google Earth, Right/JICA Study Team

Figure 11.3 Present Condition on the West Side of 4th Panama Canal Bridge

11.2.2 Existing Traffic Condition

There is a flyover connecting Corredor Norte (bound for the Bridge of the Americas) and Roosevelt Ave. Heavy traffic from the center of Panama City, the Bridge of the Americas, and towns along the Canal creates traffic congestion every morning and evening. The traffic volume on the Bridge of the Americas was observed in 2012, and the Annual Average Daily Traffic (AADT) was found to be 49,834 vehicles/day in 2 ways.

11.2.3 Obstacles

(1) Main Obstacles (Results of Site Investigation)

A flyover exists over the Omar Torrijos roundabout on the east side of the 4th Panama Canal Bridge, and the Curundu River box culvert crosses under the roundabout. To the west of the roundabout, Roosevelt Ave. is a 4 lane, 2-way traffic road with a median. It would seem to be difficult to use the existing right-of-way for the new construction due to the trees in the median strip and road side. Sosa Hill is to the southwest of the intersection of Roosevelt Ave. and the road leading to the Bridge of the Americas. The impact on this area needs to be kept at a minimum. In addition, an electrical substation building and Chill Water Plant, both managed by ACP, should be avoided as important control points (see Section 12.2.3(2)). On the other hand, there is swamp area on the west side of the 4th Panama Canal Bridge where it is noted that the ground is soft.

These obstacles are classified as follows with the corresponding measures/considerations to be taken.

Table 11.3 Measures for the obstacles

Properties to be avoided	Properties that require measures/consider
- Roosevelt Ave. - Curundu River box culvert - Sosa hill - Substation building - Chill water Plant	- Existing flyover (To be removed due to decrepitude and interference with the new ramp plan) - Omar Torrijos roundabout (To be improved considering the connectivity with the planned road) - Swamp area on the west side of the bridge (To be measured in the bridge plan)

Source: JICA Study Team

Photos of the main obstacles are shown below.


Photo 1: Beginning Point


Photo 2: River Box-Culvert


Photo 3: Omar Torrijos Roundabout


Photo 4: Flyover


Photo 5: Roosevelt Ave.

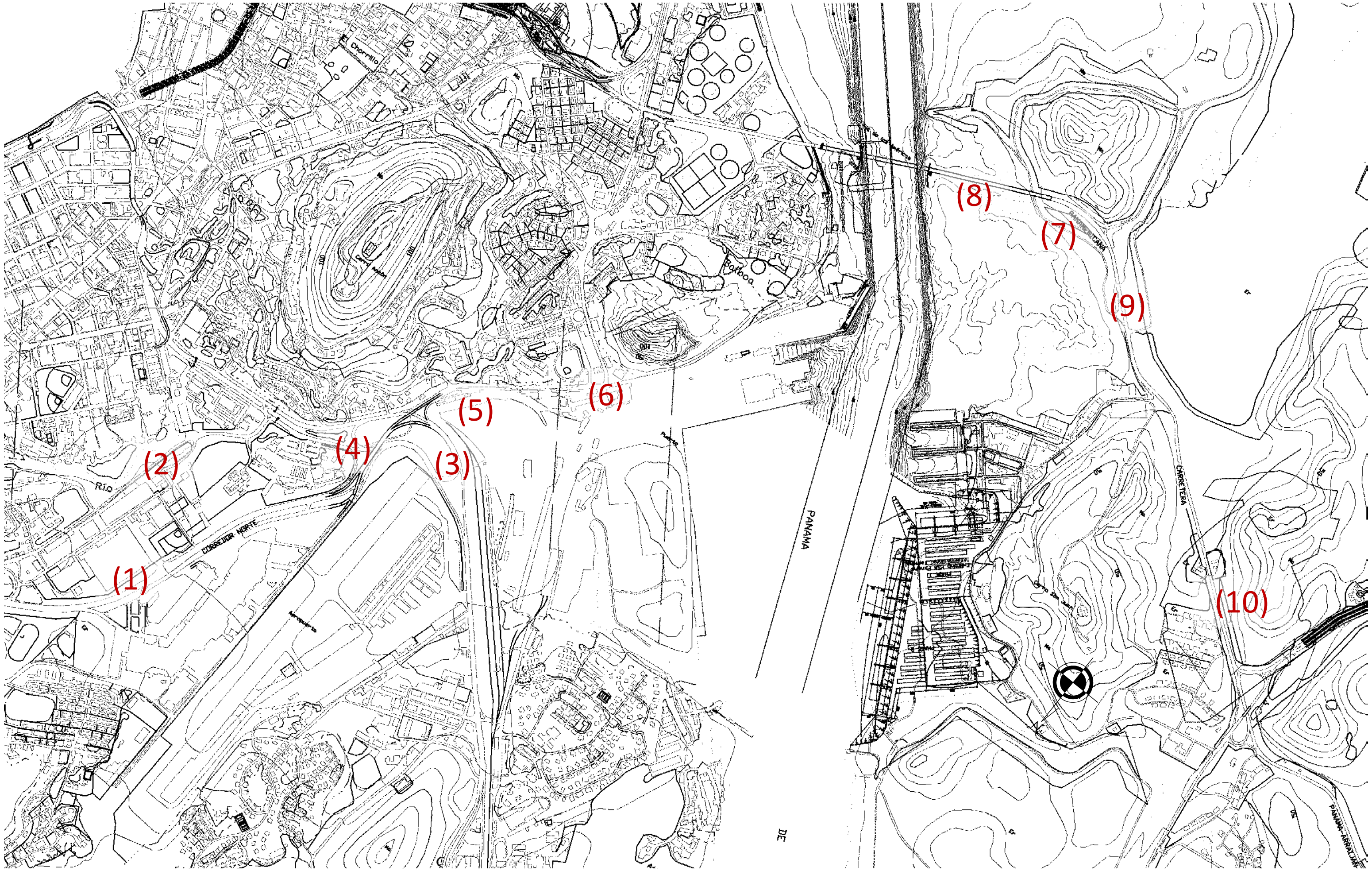

Photo 6: Sosa Hill


Photo 7: Location of 4th Panama Canal Bridge


Photo 8: Bridge of the Americas


Photo 9: Panamerican Highway


Photo 10: End Point



Source: JICA Study Team

Figure 11.4 Locations where the above photos where taken.

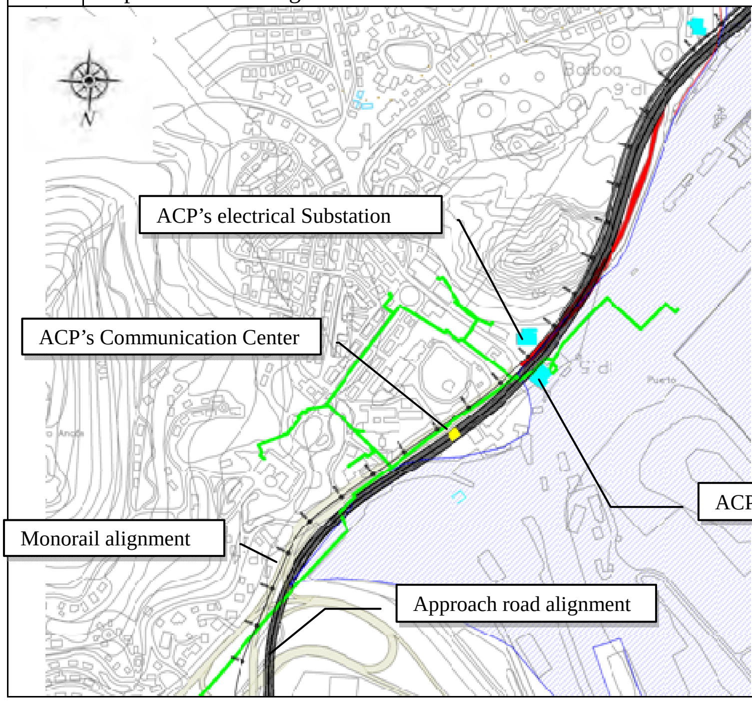
(2) Crossing Condition

Since the east side of 4th Panama Canal Bridge is close to ACP's facilities and will cross some existing roads and buried objects, the crossing condition should be considered when selecting the pier locations for the bridge.

The crossing conditions are shown in Table11.4.

Table 11.4 Crossing Condition (East Side of 4th Panama Canal Bridge)

No.	Crossing Condition	Note
	Facility to avoid	ACP 's Electrical Substation ACP's Chill Water Plant
	Facility to avoid if possible (Overpass possible but pier cannot be constructed)	ACP's Communication Center
	Area to avoid (inside the blue line) if possible	Panama Port Company
	Buried objects to avoid if possible	Chill Water Pipe
	Replaceable Existing road	



ACP's Electrical Substation

Source: JICA Study Team

(3) Navigational Condition

The navigational conditions refer to the future Canal expansion plan of ACP.

The summary of the navigational channel is shown in Table 11.5, a cross section of the future expansion is in Figure 11.5 and plan view is in Figure 11.6.

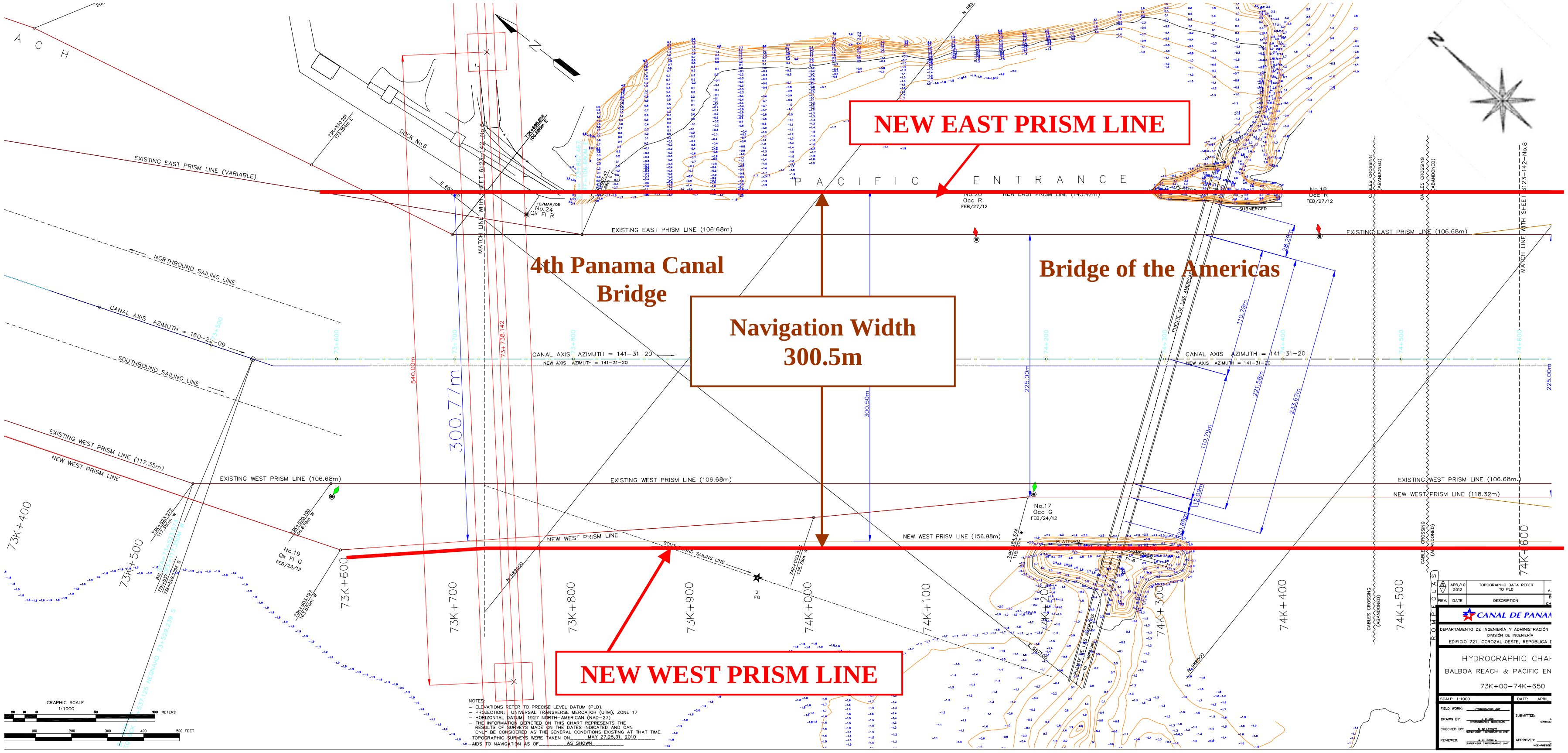
Table 11.5 Summary of the Navigation Channel

No.	Description		Requirement	Ref.
1	Horizontal Clearance	Navigable Width between Prism Lines	300.5m 1)	Figure 11.6
2		Transition Grade	1:3	-
3	Vertical Clearance	Navigable Height	75m	-
4		Above MLWS (Mean Low Water Spring)	-2.321m	-
5		Water Depth	17.62m	Figure 11.5

Note 1) The navigable width of 300.5m includes the skew angle of the 4th Panama Canal Bridge
Source: ACP

Source: ACP

Figure 11.5 Future Canal Expansion (Cross-section)



Source: ACP

Figure 11.6 Future Canal Expansion (Plan)

(4) Aviation Condition

As the specific area of the Study includes the road close to the Albrook International Airport and Howard Airport (Ex-Air Force Base), the aviation requirements were confirmed through discussions with the Civil Aviation Authority (AAC Autoridad Autonáutica Civil).

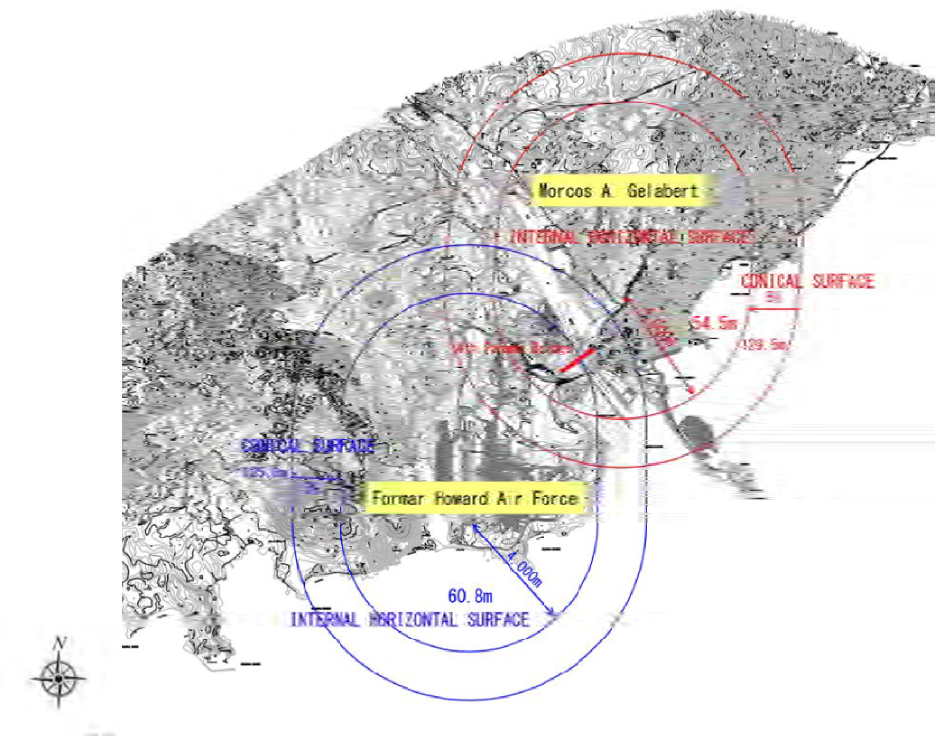
The summary of the civil aviation requirements is shown in Table 11.6, the horizontal surface plan is in Figure 11.7 and the approach surface plan is in Figure 11.8.

The horizontal surface does not ensured near the 4th Panama Canal Bridge. However, it does not affect the operation of either airports as confirming by AAC.

Table 11.6 Summary of the Civil Aviation Requirements

No.	Airport	Items	Requirement
1	Albrook International Airport (Marcos A. Gelabert Airport)	Horizontal Surface	54.5m (Radius=4km)
2		Horizontal Upper Face	129.5m
3		Gradient of Heliport Transitional Surface	14.3%
4		Approach Surface	3.3%
5		PAPI System	2.0%
6	Howard Airport	Horizontal Surface	60.8m (Radius=4km)
7		Horizontal Upper Face	135.8m

Source: AAC



Source: JICA Study Team

Figure 11.7 Horizontal Surfaces of Albrook International (Marcos A. Gelabert) Airport and Howard Airport

Source: JICA Study Team

Figure 11.8 Approach Surface and Transition Surface, Albrook International Airport and Howard Airport