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Contents

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A study on the Rubber tire maintenance case, Busan Line 4 trains

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Keyword : L.R.T, Bogie, Rubber Tire

Abstract. Busan Transportation Corporation, Railway Line 4 trains are Rubber Tire wheel type LRT vehicles. Through the early stabilization process since the March 2011 opening of an example of a successful operation. Line 4 trains is expected to be operational by sharing practices throughout the approximately four years after the opening do not have experience operating leverage to further train with rubber wheels form creation and maintenance during the useful data. As abnormal wear phenomena of the rubber tire (shoulder and beads damage) is a prime example. The purpose of this study is to discuss the development of case studies on the causes and countermeasures for the development of rubber tires vehicles

1. INTRODUCTION

Busan Transportation Corporation, Railway Line 4 trains are Rubber Tire wheel type LRT vehicles which are operated by wholly-automated operation system. Through the early stabilization process, Railway Line 4 trains have been operating successfully since opening in March 2011. Beginning with Railway Line 1, Busan Transportation Corporation has 30 years experiences in steel wheel type LRT but not in the rubber tire wheel type LRT. Thus, Line 4 trains is expected to be operated by sharing operational practices throughout the approximately four years after the opening, and the operation practice will be the useful data for rubber tire wheel type LRT system construction and maintenance.

The Bogie of steel wheel type Middle Rail Transit of Railway line 1 ~ 3 is 2 axis bogie type, while Railway line 4 is 1 axis bogie type which consists of trailing bogie and powering bogie.

Powering bogie is a bogie transmitting power of motor, while trailing bogie has no gear box serving as transmitting power.

The typical examples of abnormal wear during operation of the Railway line 4 are shoulder wear and rubber tire bead part damage that are similar with steel wheel type's grooving and abrasion.

As rubber tire is a consumable part, it should be managed taking into account the factors affecting life of consumable parts like normal and abnormal wear, and proper replacement cycle should be kept for stable train maintenance and operation.

This study is expected to be the reference for construction and maintenance of rubber tire wheel type LRT in the future by sharing the cause of abnormal wear phenomena, improvement measure and localization development case.

2. Status of rubber tire

2.1 bogie type

Railway Line 4 train of Busan Transportation Corporation consists of 6 cars, and 1 car is composed of 2 bogie. Bogie is divided into powering bogie transmitting power and trailing bogie without gear box, and using tire is same type.

The number of tire is 24ea per a train, and total number of tire managed is 408ea (24ea/train x 17 trains). Structure is shown in the Figure 1 and 2.

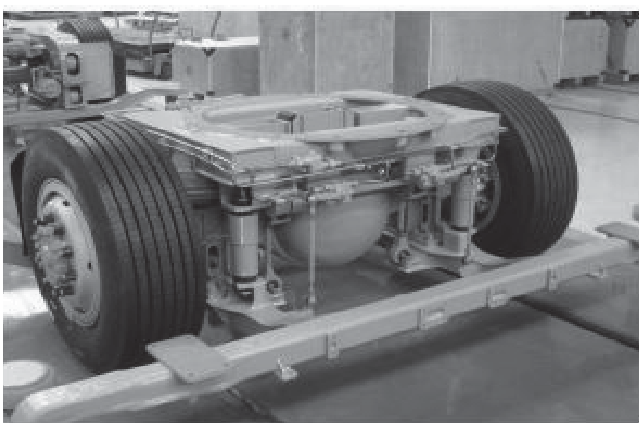


Fig. 1 Powering bogie

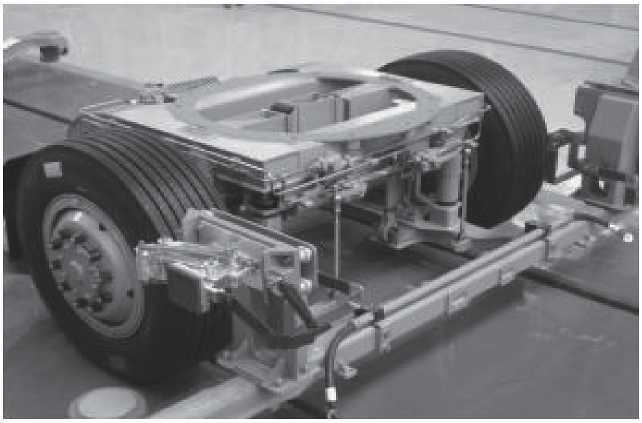


Fig. 2 Trailing bogie

2.2 Specification on rubber tire

2.2.1 Standard of rubber tire

Specifications on rubber tire are as follows:

- Standard : 315/70 R20
- Outside diameter : 946mm
- Tread depth : 15.6mm (new tire)
- Width : 310mm
- Weight : 53kg
- Working pressure : 9.5 ~ 10.5kgf/ ㎠
- Allowable Max. speed : 80km/h
- Tire ingredient : natural rubber (35%), synthetic rubber (15%), carbon (20%), metal pin (20%), etc.
- Tire replacement standard (wear threshold): When tread depth is 1.6mm (Tread 14mm)

Standard on rubber tire is shown in the Figure 3

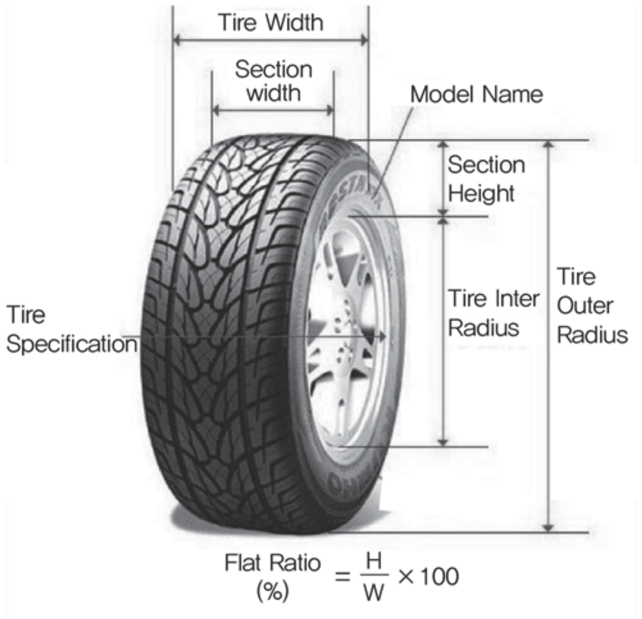


Fig. 3 Tire specification

Standard is expressed in 315/70 R20. 315 indicates cross section width, 70 indicates flatness ratio (H/W * 100). Generally, the lower flatness ratio tire is classified as high performance tire. And wear threshold mark (Figure 4) which is to confirm tire replacement time indicates that tire should be replaced when tire reaches at wear threshold mark.

Fig. 4 Tire wear indicator

2.2.2 Tire diameter by load

Internal structure of rubber tire is as shown in Figure 5, and safety wheel is installed inside. It has feature that radius is changeable by load but dynamic diameter was manufactured at 460m.

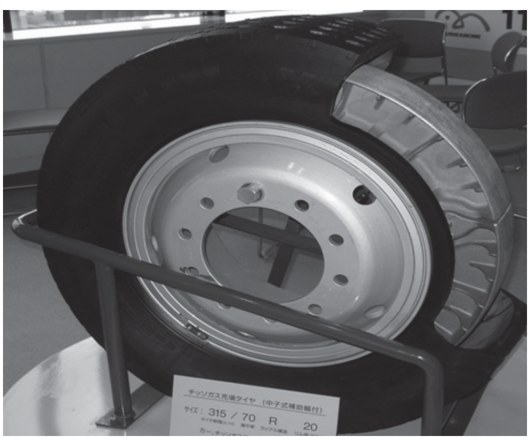


Fig. 5 Tire saction

- Tire no load radius : 473mm
- Tire empty/full weight radius : 445mm/432mm

3. Driving wheel abnormal phenomena

3.1 foreign substance sticking

Powering bogie tire　　Trailing bogie tire

Point form　　Strip form

Fig. 6 Tire surface state 1

O occurrence time: 3 month later after 2011. June

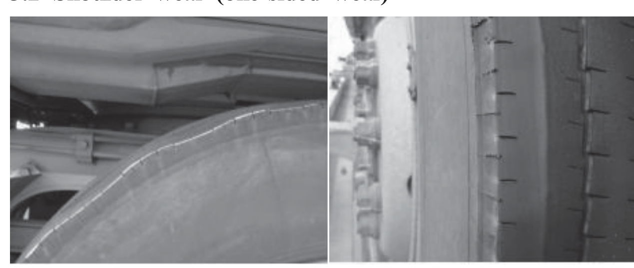
O Occurrence place: only trailing bogie driving wheel

O Cause :

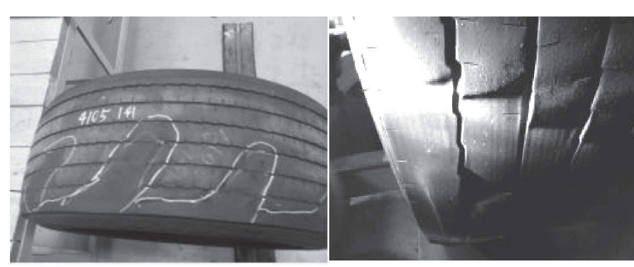
It is peculiar phenomena occurred in new line that tire wear particle remained in the track sticks to tire. There is no effect on tire life and it disappears once wear amount decreases.

In case of powering axis tire, wear particle does not stick to the tire because tire surface is worn down by driving torque during shuttle service. Powering axis tire tends to be worn down more 10 times than trailing axis tire.

3.2 Shoulder wear (one-sided wear)



Uneven wear 1　　Uneven wear 2



Uneven wear 3　　Uneven wear 4

Fig. 7 Tire surface state 2

O occurrence time: 2012. Feb. (Nov. after the opening, 102 case founded)

O Occurrence place: trailing/powering driving wheel

For consideration on shoulder wear, consideration on tire structure, name, abnormal wear phenomena is required.

3.2.1 Tire structure and name

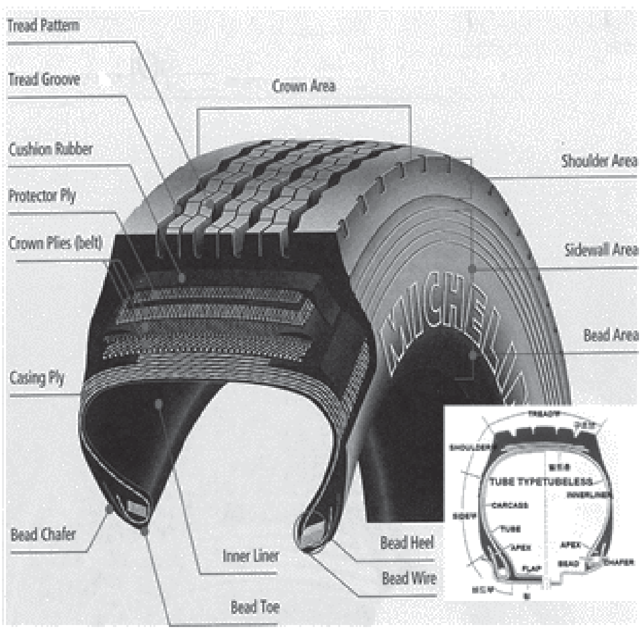
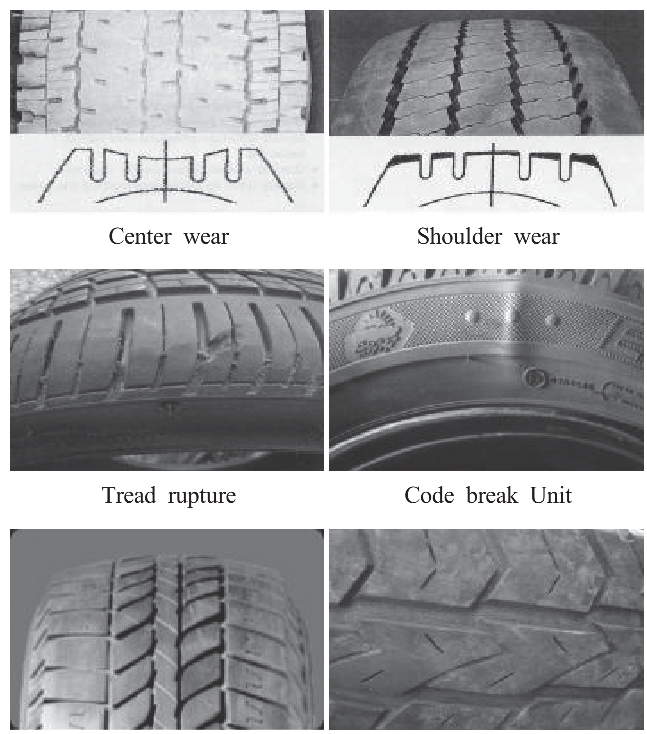


Fig. 8 Tire section

- ❍ Tread
  It means the section contacting the road, and made of thick rubber layer. This rubber layer serves as internal carcass protection against external impact and damage
- ❍ Shoulder
  It means the rubber layer located in Edge section between Thread and side wall, and serves as thermal emission occurred in driving as well as carcass protection
- ❍ Side Wall
  It means the reinforced section whose shape is like ring with topping by rubber, and serves as fixing tire ,which put air at high pressure, to rim.
- ❍ Bead
  It means the layer which is wrapped by bead wire and overlapped by rubber topping code. It has two types, bias and radial, according to cass arrangement angle.
- ❍ Carcass
  It means the forming section which covers rubber to both side of code with tire framework.
- ❍ Cord
  It means the code included in the tire rubber layer due to the absence of strengthen consisting of framework of tire, and serves as important role that supports loading of air pressure and tire weight as well as enhancement of tire's durability and high speed handling stability.
- ❍ Belt
  It means the band serving as enhancing hardness of tread by strongly tying tread and carcass of tire.

3.2.2 Abnormal wear phenomena and types



Center wear | Shoulder wear
Tread rupture | Code break Unit
Spot wear | Tire cracking

Fig. 9 Tire damage type

- ❍ Center wear (Center wear)
  Phenomenon: Faster wear of Tread center part than Shoulder part
  Cause: Over-filling of tire pressure
- ❍ Shoulder wear
  Phenomenon: The outer part or some part of the bottom surface of tire is constantly worn down in the circumferential direction, The tread is weighted to Shoulder part and both edges of tread is worn down

Cause: Over-filling of tire pressure compared with vehicle weight

- ❍ Spot wear (spot wear)
  Phenomenon: local wear without distinguishing the outer or inside part of the bottom surface of tire
  Cause: Local excessive wear because of sharp braking (bending of the axle or eccentricity of the driving wheel)
- ❍ Tread rupture
  Phenomenon: breakage or damage of tread because of big impact on tire by foreign object while driving
  Cause: impact by foreign object (an iron whip, stone etc) in driving road
- ❍ Cord Knifing
  Phenomenon: timidness because of knifing of metal pin cord of Shoulder part or Sidewall
  Cause: Damage due to a strong external shock or trauma
- ❍ Tire cracking
  Phenomenon: Fine cracks on the tire surface
  Cause: elapse of tire validity or damage on tire due to chemicals

3.2.3 General wear phenomena due to air pressure

- ❍ General wear phenomena due to air pressure
  If the tire does not contain a proper air pressure, it cannot achieve 100% of its performance. If the air pressure level or tire is low, the tire is quickly worn down. If the tire keep being used, it is hard on the tire and causes an unexpected accident.

1) Tire damage due to the Lack of air pressure

The low level of air pressure causes to aggrandize the movement of tire, and an abnormal heating on the tire is generated which weakens the cord or rubber and causes damages or phenomena as blow.

① Separation or cord cutting due to heating
② Easy breakaway of tire bead from wheel
③ Fast abnormal wear (both edges of tire)
④ Fast aging process due to overheating of tire
⑤ Fast damage to bead due to friction between wheel and tire bead.

2) Damage to the tire by the over air pressure

The over air pressure makes the tire nervous and falls buffering capacity.

① Easy rupture due to the impact of easy knifing
② Fast abnormal wear(Center wear of tire)

3) Proper air pressure maintenance

It is critical to maintain the proper air pressure. The air pressure should be injected by equalizing the ground contact pressure of tread in order to avoid one-sided wear, minimize resistance movement due to rotation. It also minimizes the heat generation and ejects the heat to maintain safely the internal temperature of tire. In other words, the proper air pressure can maximize tire performance in terms of safe driving, riding comfort and in economic terms.

3.2.4 Limit of use of tire with Shoulder wear

- ❍ Even if the Shoulder wear on one side of driving tire wheel, the tire can be used until the limit of Fig 10. In case of use with the Fig10 limit excess, the metal fin that supports the tire is exposed at the surface, than should be exchanged. The limit is the surface of Cushion Rubber applied to the base of Tread Rubber.

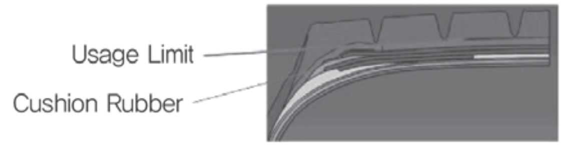
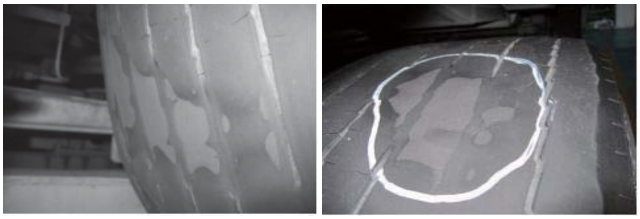


Fig. 10 Tire wear indicator

- ❍ In case of Shoulder wear or excess of limit state of wear or Shoulder
  It is very dangerous when the metal pin that supports the tire is exposed due to Shoulder wear on edge of Tread.



Cushion rubber exposure

Core exposure

Fig. 11 Tire surface state 2-1

○ Comparison of FOOT-PRINT form in accordance with the weight and air pressure level

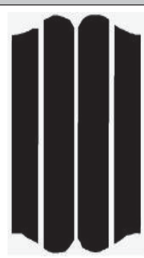
①	②	③
		
Low loading - too high pressure	Low loading - Lower pressure	Nominal usage

Fig. 12 Tire foot print 1

○ Comparison of FOOT-PRINT state in accordance with the contact area

high pressure	Lower pressure
	
Load 3,150㎏ pressure 8.5 bar	Load 2,250㎏ pressure 8.5 bar

Fig. 13 Tire foot print 2

In case of low weight and high air pressure, the contact area between the road and bottom of tire is getting less and the Shoulder wear can be caused while driving.

3.2.5 Review of proper air pressure of driving wheel of Busan Subway Line 4

Table 1 Train load

Division	Load Ratio	Load on Tire
Empty	50%	2785~3000㎏
Normal	48%	3750㎏

The actual air pressure of driving wheel(10.5㎏/㎠) is filled with a high pressure than the operating conditions because it is set with a condition of full weight of train. This condition is similar to the operation condition in rush hour that presents about 1 − 2 % of total operation. In a consideration of the full complement weight(48%) and weight of empty train, the air pressure of tire is set to 9.5㎏/㎠ after exchanging the new tire in order to minimize Shoulder wear. The air pressure management is modified to manage as below.

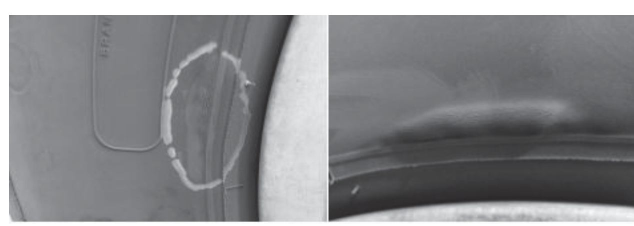
Table 2 Pressure evolution

Pressure evolution : 9.2bar at 17℃							
℃	-10	0	10	17	25	30	35
bar	8.5	8.9	9.2	9.5	9.8	10.0	10.2

3.3 Damage to bead of driving wheel

○ Time: March. 2012 (1 year after opening, 130 cases occurred)

○ Part: Damage to bead of driving wheel(excess of stress limit)



① Bead damage 1 → ② Bead damage 2

③ Bead damage 3 → ④ Bead damage 4

Fig. 14 Tire surface state 3

❍ investigation of cause

The damage of tire bead is occurred by a crack proceeding from inside, rather than outside damage.

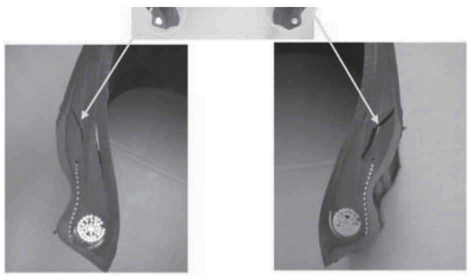


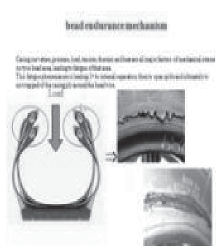
Fig. 15 Tire bead section 1

❍ Cause

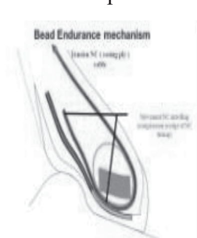
The crack is occurred by accumulating a stress on the bead due to the application of over tension on wire of casing ply inside of tire

Separation is gener rated

Internal separation

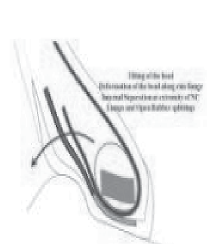


Deformations and open splits



Movement of the casing ply

Compression on the bead seat



Separations, deformations and open splits

Fig. 16 Tire bead section 2

❍ Solution: Promoting a design supplement for metal pin of bead

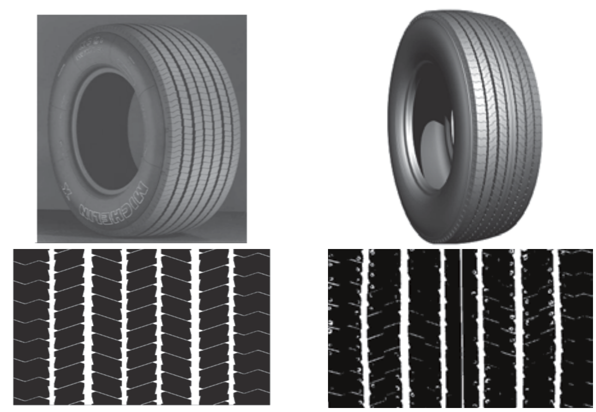
※ promoting a supplementation of bead in tire localization development phase

※ Completion of application of localized developments: may, 2013

4. Domestic Development of Driving Wheel

4.1 Specification and configuration of domestic parts

❍ Comparison of tire configuration and pattern



Michelin tire Kumho tire

Fig. 17 Tire comparison

※ Applied Zigzag Sipe to minimize abnormal wear on the straight Rib similar to Michelin

Table 3 Tire spec. comparison

Division	Michelin	Kumho
Spec.	315/70 R20	315/70 R20
RIM (Wheel)	20-8.50	20-8.50
Pressure(kgf/㎠)	10.5	10.5
d(㎜)	946	946
w(㎜)	310	310
Tread w(㎜)	260	264
load(㎏)	4,150	4,150
Deformation(㎜)	35.0	38.0
r(㎜)	438.0	435.0
Tread depth(㎜)	15.6	15.5
weight(㎏)	53.0	56.0
Max. V(㎞/h)	80	80

The rubber tires of Line 4 trains are imported and expensive with long delivery time. The domestic development was very important in order to minimize the operation cost and maintain smoothly the trains

The localization was developed by Woojin Industries, Ltd, a vehicle manufacturing company, and Kumho Tire, a tire manufacturing company, produced the prototype with specification and configuration of Fig17 and Tabl2 3.

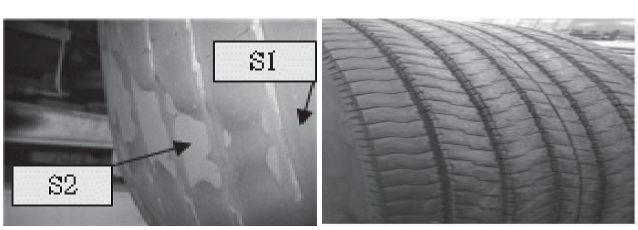
The on-track test to domestic developments was conducted from October 26, 2011 to October 29 2012 within 1 year. The distance of on-track test was 82,568km. After the test, the abnormal wear such as Shoulder wear or damage to bead was not occurred. Also, it was conformed that the wear performance of domestic developments had a same quality level of existing product as shown in Table 4, monthly (based on 7,000km) 5.05mm wear of existing product and 4.9mm wear of domestic development. Therefore, since may 2013, the domestic developments was applied.

Table 4 Tire wears

Division	Michelin		Kumho	
	right	left	right	left
Wear(mm)	5.1	5.0	4.9	4.9

4.2 Performance Improvements of Localized Developments Driving Wheel

The domestic developed rubber tires of Line 4 trains was applied since may 2013 until present (may 2015) within 2 years with 200 units. As a result of its application, any abnormal wear was not occurred. The hardness of rubber tire surface of existing product and domestic developments was checked as shown in Fig 18. The test result conformed that the rubber hardness of existing product with Shoulder wear was 70 ~ 77, and the rubber hardness of domestic developments was 66 ~ 70. It confirmed that the Shoulder wear is related with the hardness.

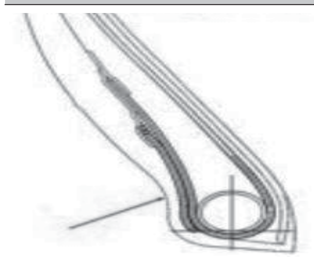
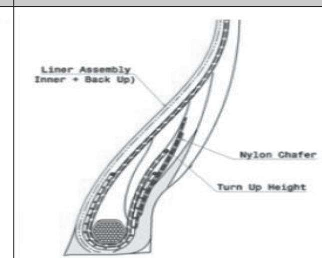


Michelin Kumho

Fig. 18 Tire surface state 2

Specially, the bead damage that is occurred frequently in existing product was not occurred in domestic developments. It confirmed that the application of nylon type Chafer as shown in Table 5 to prevent bead damage was found very useful for Busan Metro Line 4 that contains many severe curves as shown in Fig 19.

Table 5 Tire bead seat comparison

Michelin	Kumho
	
Turn Up Height : 50mm	Turn Up Height : 50mm
Thickness : 4.0mm	Thickness : 4.7mm
Chafer : Rubber	Chafer : Nylon

Michelin Kumho

Fig. 19 Tire surface comparison

5. Management of Driving Wheel

5.1 Driving wheel consumption measurements

Table 6 Tire wears & Life cycle

Division	wear(mm/month)		life cycle(1,000km)	
	T-Bogie	M-Bogie	T-Bogie	M-Bogie
2011	0.29	1.81	340	54
2012	0.09	0.91	1,000	108
2013	0.01	0.52	9,800	190
2014	0.01	0.47	9,800	210

The driving wheel of LRT vehicles of rubber wheel type should be constantly managed through examining the amount of wear due to the impact of road conditions and checking its exchange period. After the opening, the amount of tire wear has been annually checked and its measurements are shown in Table 6.

By analyzing the wear trend of rubber tire, it was verified that the driving wheel of east axle has the early wear 10 times more than driving wheel of trailing axle, and the life time of driving wheel of east axle at the beginning was 54,000km which is getting longer and now it is 210,000km. It seems to be longer.

With the consideration of the rubber material of driving wheel of trailing axle, it is difficult to use this unlimitedly, so the interchange method that exchanges the location to east axle when the periodic inspection of median line, is applied.

The principle of interchange method is to exchange to trailing axle when the depth of driving wheel of east axle reach at 6.6±1mm in order to manage effectively. The interchange method is as shown in Fig 20.

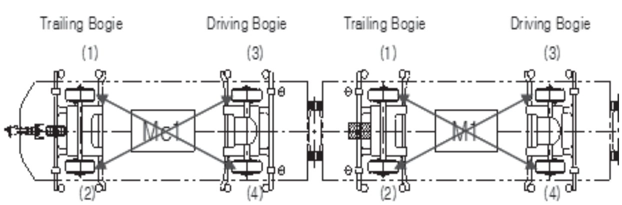


Fig. 20 Tire interchange

6. Conclusion

This investigation is a study about maintenance case of LRT vehicle's rubber tire with rubber wheel type. Regarding the rubber tire's life time, it was verified that the exchange life time of rubber tire is constantly getting longer as the operating time increases, when the wear is occurred normally.

Also, regarding the abnormal wear phenomenon, the representative instances are Shoulder wear and bead damage. As a solution, it was verified that the domestic developed rubber tire does not present such problem. The occurrence of abnormal wear is related to air pressure, rubber hardness and the application of bead Chafer.

I hope this study would be used as a reference for the construction and maintenance of LRT vehicle with rubber wheel type.

Reference

1. Hang Woo Kim, Tire Engineering Tire Structure, Golden Bell (p39~45)

2. Hang Woo Kim, Tire Engineering Tire Wear Characteristic, Golden Bell (p73~74)

3. Hang Woo Kim, Tire Engineering Tire Footprint Test, Golden Bell (p112)

4. Hang Woo Kim, Tire Engineering Tire Abnormal, Golden Bell (p143~144)

Study on the Calculation of Safe Sidetracking Time for the Local Train using Blocking Time Model

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Keyword : Blocking time model, Blocking time stairway, Sidetracking time, Mixed traffic line, Conflict

Abstract. It is increasing interested in the introduction of an express train to enhance the competitiveness of the railway. If the express train would be introduced in a certain line on which only local trains run, sidetrack is needed for the express train to overtake local train. In addition, it is also very important to properly set the sidetracking time of local train in terms of ensuring safety of rail traffic flows. This paper explains the calculation method of safety sidetracking time for the local train on the shunting station using the blocking rime model. And then, a case study shows the operation of the mixed train traffic using overnight-staying track of SMRT Line 6. It includes the estimation of safety sidetracking time for local train and the possible operation plan for the conflict-free local & express traffic flows.

1. INTRODUCTION

Recently, introduction of express trains attracts attention to improve the competitiveness of railroad. If express trains are introduced into the local train-only line, sidetracking line for local trains is required for overtaking operation of express trains and safe sidetracking time of local trains should be appropriately determined in order to ensure efficient use of track capacity and safe train flow.

Sidetracking time of local trains is determined to give a certain value to safe arrival/departure headway between trains as shown in Fig. 1. In the actual railroad operation, however, sidetracking time varies for each sidetracking point according to train sequence, position of a turnout, signaling system, blocking length, turnout passing speed, etc..

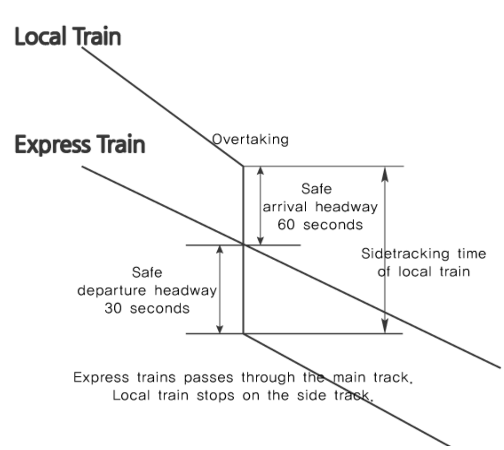

Fig. 1 Application example of safe sidetracking time

This paper intends to describe how to calculate safe sidetracking time of local train in sidetracking stops by using blocking time and blocking time stairway model. Next, safe sidetracking time of local train in case of mixed operation of slow and express trains by using overnight staying tracks of SMRT Line 6 is estimated as a case study and a method of mixed operation without conflicts is proposed.

2. Blocking Time Model

2.1 Blocking Time and Blocking Time Stairway[3]

For effective management of railroad capacity, analysis model is required which can accurately describe how railroad infrastructure is used for operation in the course of train movement. One of these analysis models is blocking time model.

Blocking time is total time taken for one train to occupy exclusively and pass section of track1). Therefore, another train is blocked to enter this track section for this time. Blocking time continues from the time a train is granted movement authority to enter the blocked section to the time the train has passed the section and entire signal system returns to normal state. Therefore, occupying time of blocked section is longer than the actual occupying time of this section. For lineside signal, blocking time of this section consists of time elements as shown in Fig. 2.

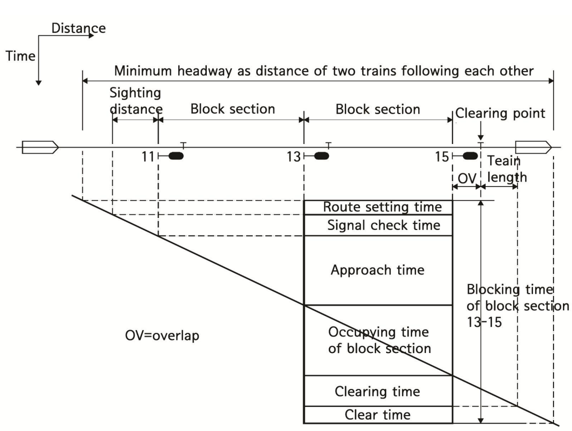

Fig. 2 blocking time of a block section [3, p.4]

1) For example, there are blocked sections, interlocked routes, etc.

T = T1 + T2 + T3 + T4 + T5 + T6

T : Blocked Occupying Time
T1 : Route Setting Time
T2 : Signal Check Time(Time to check aspect information of the signal which provides approach direction for the signal installed at the entrance of the blocked section which a train will enter)
T3 : Approach Time(Time for a train to move from the signal which provides approach direction to the signal at the entrance of the blocked section which the train will enter)
T4 : Occupying Time of Blocked Section
T5 : Clearing Time of Blocked Section(Overlap + Clear Time for Train Length)
T6 : Clear Time for Blocked Section Route

For cab signal, the basic principle is the same as lineside signal but the approach time is time for the train to pass the braking distance shown by the cab signal system. Blocking time of all blocked sections in a certain line is shown as blocking time stairway in the time-distance diagram. Minimum headway for two preceding/following trains is determined by preventing the overlap of train blocking time at any point within the operation section and making them contact to each other.

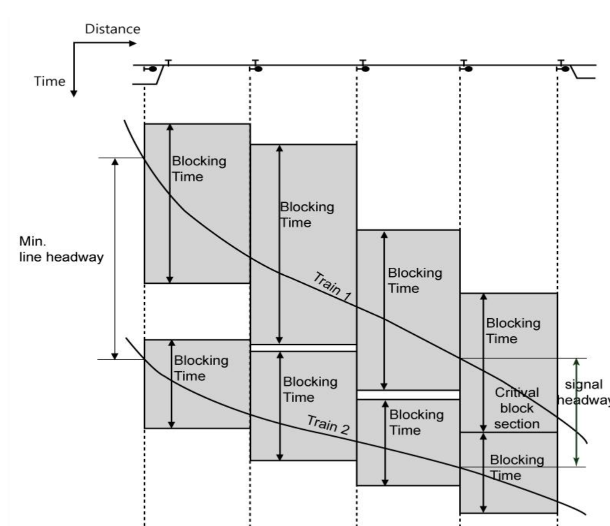

Fig. 3 Blocking time stairway of two trains following each other, minimum line headway and signal headway of critical block section [3, p.5]

2.2 Approach Time of Multi-Aspect/Multi-Blocking Signal System[2]

Blocking signal system can be classified into multi-aspect signal and multi-blocking signal. Understanding this classification is important to calculate blocking time, specifically, approach time. For three-aspect blocking signal systems, a train receives three, consecutive signals of clear, approach and stop when it approaches a stop signal. Generally, this three-aspect signal system is linked with two blocking signal systems. It means that all signals can show all of three signal aspects and therefore, information of the two blocked section in forward direction is provided (refer to Fig. 4B) But, three-aspect signal system can be implemented as two aspect signal and it can be implemented by installing assist signals at the starting point of forward braking distance for all blocking signals. (refer to Fig. 4 A)

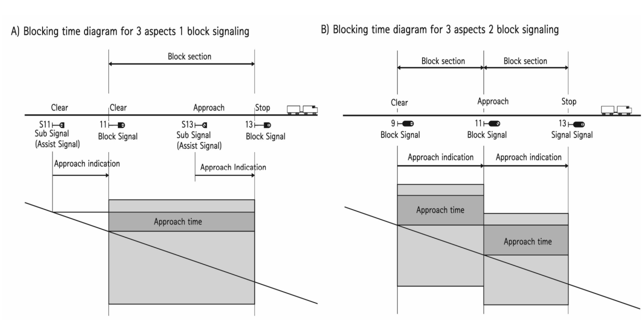

Fig. 4 Different kinds of 3-aspects block signaling [2, p.4]

Block signals can show stop/pass and assist signals can show approach/clear signal. Therefore, a train approaching a stop blocking signal receives three consecutive signal aspects of clear, approach and stop as mentioned above. But, this signal arrangement is a single signal system, not two blocking signal system. The blocking signals provides information on forward blocked section but aspects of the assist signal cannot provide information on the next blocking signal. As approach time is a part of blocked occupying time, approach aspect time has to be given as late as possible. Otherwise, it may decrease track capacity. The approach time starts at the time of passing the assist signal in a single blocking signal system and it starts when the front of a train passes the blocking signal just before the blocking signal which is located at the starting point of a blocked section which the train will enter in double blocking signal system.

In four-aspect blocking signal system, a train receives four consecutive signal aspects when it approaches the stop signal. In this signal system, the driver will get information on three blocked sections in forward direction. This means that this signal system has three-blocking signal system as a basic principle. Decision on from which signal the approach time starts is an important matter when analyzing the blocking time of a line to which four-aspect signal system. The start point of approach time depends on train speed and braking distance. From a signal which shows 'warning' aspect, the driver will get information that the next signal will show 'stop' aspect.

For a train which has braking distance longer than the length of a blocked section or if train speed is higher than the speed specified by 'warning' aspect, approach time starts when the train passes the 'warning' aspect signal (refer to Fig. 5 A). On the contrary, if braking distance does not exceed the length of blocked section or train speed is lower than the speed specified by 'warning' aspect, approach time starts from the 'approach' signal. (refer to Fig. 5 B) Staggered speed signaling has disadvantage that a train should slow down to specified speed but it is very useful in a line with short blocked section.

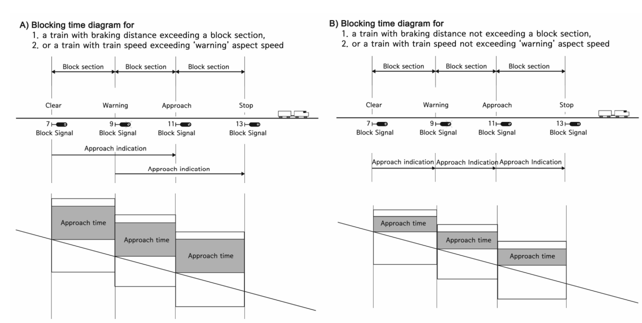

Fig. 5 4-aspects signaling with an approach aspect or approach limited speed aspect [2, pp.5~6]

2.3 Overlap[2]

Block overlap is a common safety element which is applied to railroad that operates high-density passenger trains. The aim of block overlap is to protect trains from an overspeed train which has not stopped before 'stop' signal due to the lack of braking distance by errors in braking or checking signals. The basic concept of overlap is that control lengths of continuous block signals overlap each other as much as specific length.

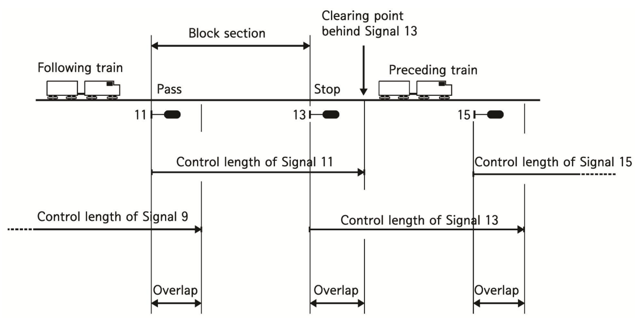

Fig. 6 6 Block overlaps in a fixed block system [2, p.7]

As block signal can only be cleared of 'stop' aspect when all of overlaps following the corresponding block section and the exit signal of the block section are cleared of train occupancy, a train which approaches a 'stop' aspect signal will always have clear overlap next to the signal. That is, for blocking time of overlaps, specifically blocking time of an overlap which includes a shunting switch within a stop section, another train path cannot be set which passes the overlap. Overlap can be cleared after a train has passed the exit signal of the preceding block section and the route of the block section has been completely cleared or a train has stopped at the blocked section. Therefore, blocking time of overlap can be ended when the blocked section occupied by a train remains occupied. Fig. 7 shows the addition of blocking time of overlap to the blocking time graph.

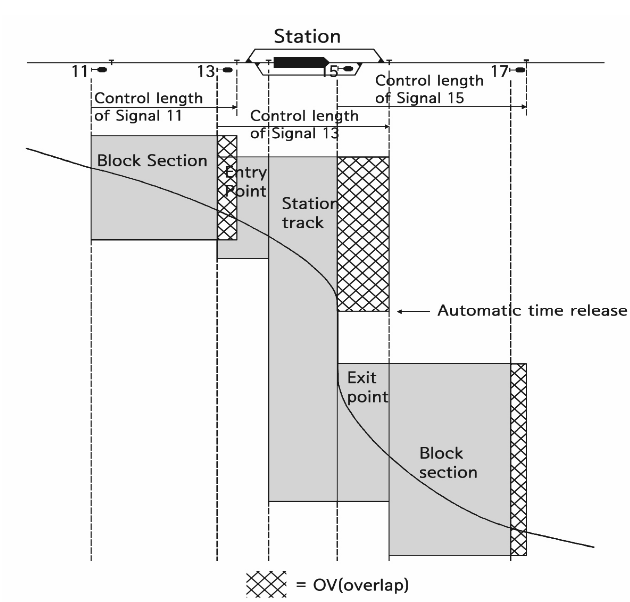

Fig. 7 Overlaps in the block time graph [2, p.8]

3. Calculation of Sidetracking Time of Local Trains

To prevent route conflicts between the preceding local train and following express train in the line of mixed operation, sidetracking of the local train and overtaking of the express train are required as shown in Fig .8 at the intermediate station where a submain line is installed.

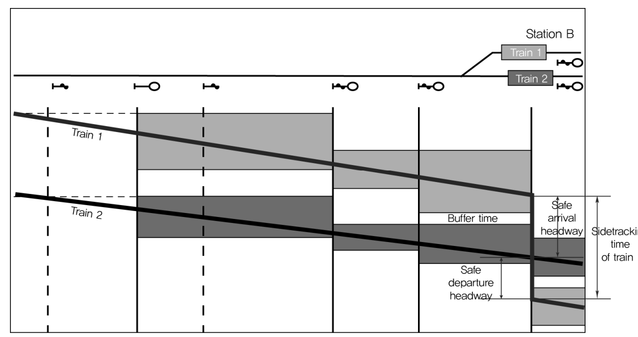

Fig. 8 Safety sSafe sidetracking time using blocking time stairway [1, p.268]

Fig. 8 shows a situation where express train 2 follows local train 1 in a sing line track. Speed higher than that of train 1 can be found from the fact that train 2 has narrow blocking time and gradual slop of train operation line. Although buffer time is placed between routes of the trains, this time is not enough to clear conflict between them. So, train 1 moves to submain line of stop B and train 2 overtakes train 1, passing through the main line.

In this case, setting minimum headway between local train and express train in stop B is important to safe operation of trains and efficient use of railroad facilities. If safe arrival/departure headway is set to be short, route conflicts may occur, obstructing safe operation and if it is too long, the operation time of trains decreases and track capacity cannot be used efficiently. Therefore, minimum headway between trains should be determined by preventing blocking time stairway and occupying time of overlaps from overlapping and making them contact at minimum one point. As buffer in headway time is added in actual preparation of operation schedule, headway for safe arrival/departure between local train and express train should be set as shown in Fig. 8 while keeping distance between trains as long as [headway time plus buffer time].

In this case, even if conflicts do not occur as blocking stairway diagrams of trains do not overlap in the blocked section of the stop where operation sequence of two trains is changed, blocking time and overlap time according to the signal system may overlap in the main line. Therefore, train headway should be determined by considering route conflicts in the main line before and after the blocked section of the stop where overtaking occurs.

4. Case Study: Examination on Operation of Local and Express Trains by Using Overnight Staying Tracks[2)]

4.1 Line for Examination

As most of Korean urban railroad lines except garages consist of underground or overhead structures, there are limitations in costs and installation method to install sidetracking lines necessary for operation of express trains. There are stations in urban railroad lines for train departure or arrival and these stations have overnight staying tracks for train parking. These tracks are used for train parking for night time and also used to keep train intervals by train departure from intermediate departure stations during dawn. They are also used as return tracks for trains which has ended operation at intermediate end stations but are not used during day time which give the possibility of use for sidetracking of local train if express train is introduced.

This paper has examined the possibility of mixed operation targeted for SMRT Line 6 if express trains are introduced by using the existing overnight staying tracks of urban railroad infrastructure. SMRT Line 6 is a line which connects the north of Han River horizontally where 28.1km of Bongwhasan to Eungam section is operated in double line and 7.0km of Eungam-Dokbawi-Eungam section is operated as a single line loop. Currently, trains of this line are operated as local trains which stop at all stations. It takes 57 minutes and 13 minutes to travel Bongwhasan to Eungam section and Eungam-Dokbawi-Eungam section, respectively. It takes 2 hours and 7 minutes for one round travel of Bongwhasan-Eungam-Dokbawi-Eungam-Bongwhasan.

As shown in Fig. 9, overnight staying tracks of SMRT Line 6 which can be used for sidetracking of local trains are installed in four locations of Sangwolgok Station, Daeheung to Gongduk section, Eungam to Saejeol section and Dokbawi Station.[3)]

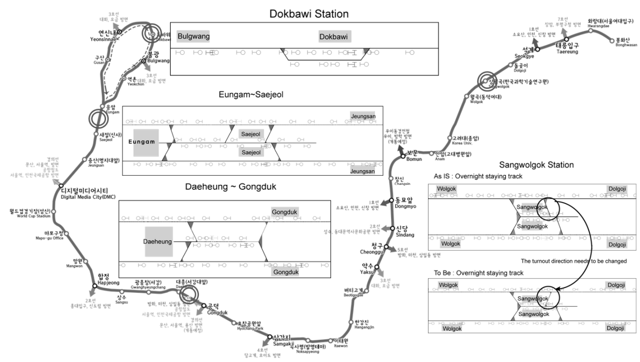

Fig. 9 Overnight-staying tracks of SMRT Line 6

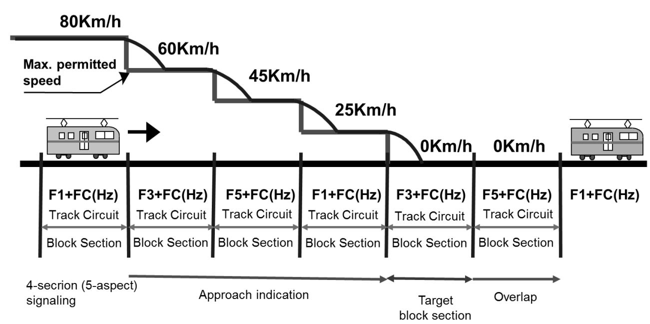

Fig. 10 Signaling system of SMRT Line 6

As SMRT Line 6 has different speed codes according to the location of the preceding train for each track circuit, one speed code system cannot be defined which is applied to all lines. As it is difficult to examine speed codes for each track circuit, however, it is assumed that four blocking (five aspects) signal system is operated and the absolute stop (R0) blocking section is overlaps.

4.2 Examination on Sidetracking Time of Local Trains at Shunting Stations

This paper used Railsys® ver.7.9.14, a program for train operation analysis, to establish the infrastructure of SMRT Line 6 and examine the possibility of mixed operation of local and express trains.

Fig. 11 and 12 show the result of minimum sidetracking time calculated for Dokbawi and Sangwolgok Stations where

2) The result of case examination in this paper is opinion of the author and may be different from that of SMRT.

3) The turnout direction needs to be changed to ensure that Sangwolgok Station up train (Dolgoji→Wolgok) performs sidetracking to overnight staying tracks. Although there is overnight staying tracks in Hanganjin Station, it is excluded from usable facilities as it is difficult to install a turnout in the curve section.

sidetracking of local trains is expected to occur.

- Dokbawi Station(Bulgwang→Yeonsinnae)
  Minimum safe arrival: 76 sec, minimum safe departure: 89 sec
  Minimum sidetracking time for local trains: 165sec(2 min. 45 sec)
- Sangwolgok Station (Bongwhasan→Eungam)
  Minimum safe arrival: 43 sec, minimum safe departure: 42 sec
  Minimum sidetracking time for local trains: 85 sec(1 min. 25sec)

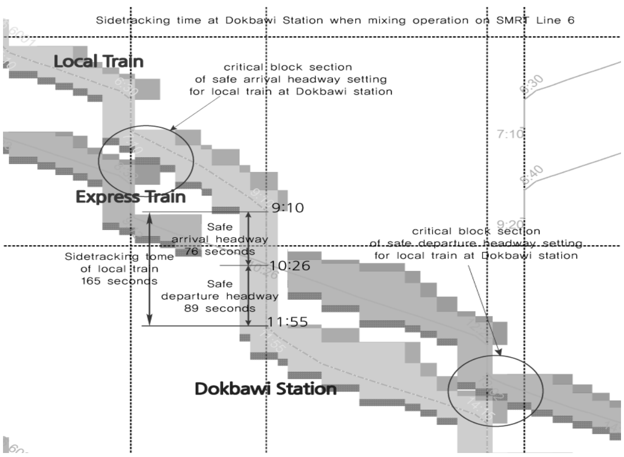

Fig. 11 Minimum Sidetracking time at Dokbawi

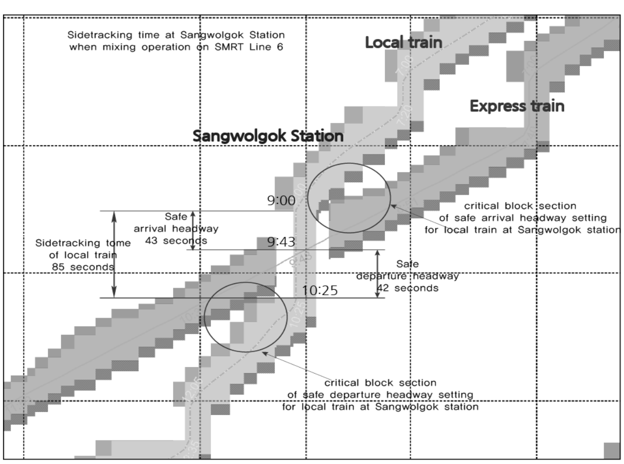

Fig. 12 Minimum Sidetracking time at Sangwolgok

As shown in Fig. 11 and 12, critical block section of headway setting in calculating minimum safe arrival/departure headway is block section where blocking time stairways of local and express trains make contact each other before and after sidetracking stations (Dokbawi and Sangwolgok Stations). Therefore, conflicts between trains shall be examined for the blocking time stairways of all block sections of the sidetracking stations as well as stops before and after the stations to determine sidetracking time of local trains at sidetracking stations.

4.3 Examination on Possibility of Mixed Operation of Local and Express Trains

This paper assumes that local and express trains are introduced at the ratio of 1 to 1 to examine the mixed operation of them for SMRT Line 6. It is also assumed that local trains keep the existing station stop schedule. Operation time announced on the SMRT Web site is applied to the operation time of local train s and for operation time of express trains, 7% of buffer time is added to simulated operation time and then converted to operation time in the unit of 10 sec for application.

1) Analysis scenario 1

Scenario 1 assumes that 12 trains depart from Bongwhasan Station for 1 peak hour with 5 min of average headway.

- Headway between local train and express train: 3min
- Headway between express train and local train: 7min

For operation pattern of express trains for peak time before noon in scenario 1, stop stations are significantly decreased in the direction of city center for fast arrival and they are increased or stops are made at all stations in the direction of the outskirts as shown in Fig. 13.

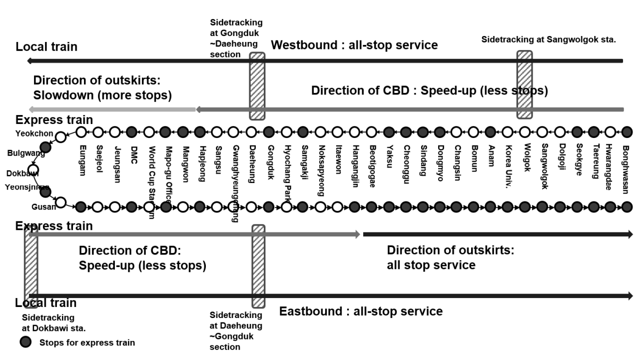

Fig. 13 Mixed traffic scenario 1 of SMRT Line 6

Local trains stop at all stations and as shown in Fig. 14, local trains in the direction of Bongwhasan → Eungam → Dokbawi performs sidetracking at Sangwolgok Station and overnight staying tracks of Gongduk-Daeheung section. In the direction of Dokbawi → Eungam → Bongwhasan, local trains need to avoide express trains at Dokbawi Station and overnight staying tracks of Daeheung to Gongduk section. As the trains in both directions perform sidetracking in overnight staying tracks of Gongduk-Daeheung section, it has been found that train operation time needs to be changed.

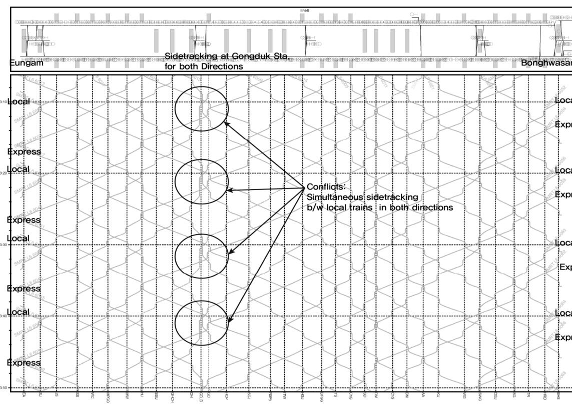

Fig. 14 Train schedule according to mixed traffic scenario 1

2) Analysis scenario 2

To prevent conflict due to simultaneous sidetracking of up and down local trains at Gongduk to Daeheung section, scenario 2[4] sets operation pattern that trains in the direction of Bongwhasan→Eungam switch the operation method for local and express trains at Eungam Station. For operation pattern of express trains, stop stations are significantly decreased in the direction of city center and stops are made for up and down trains at all stations in the direction of outskirts.

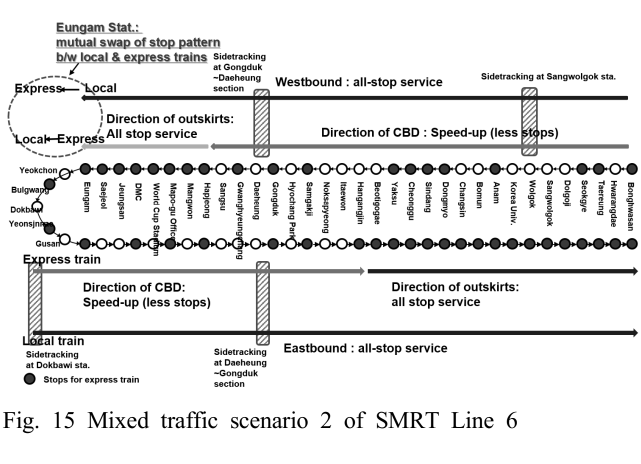

Fig. 15 Mixed traffic scenario 2 of SMRT Line 6

As in scenario 1, local trains stop at all stations and performs sidetracking at Sanwolgok Station and Gongduk to Daeheung section in the direction of Bongwhasan → Eungam → Dokbawi at Dokbawi Station and overnight staying tracks of Daeheung to Gongduk section in the direction of Dokbawi → Eungam → Bongwhasan.

In this method, simultaneous sidetracking of local trains at overnight staying tracks of Gongduk to Daeheung section was cleared contrary to scenario 1 to remove conflicts between trains.

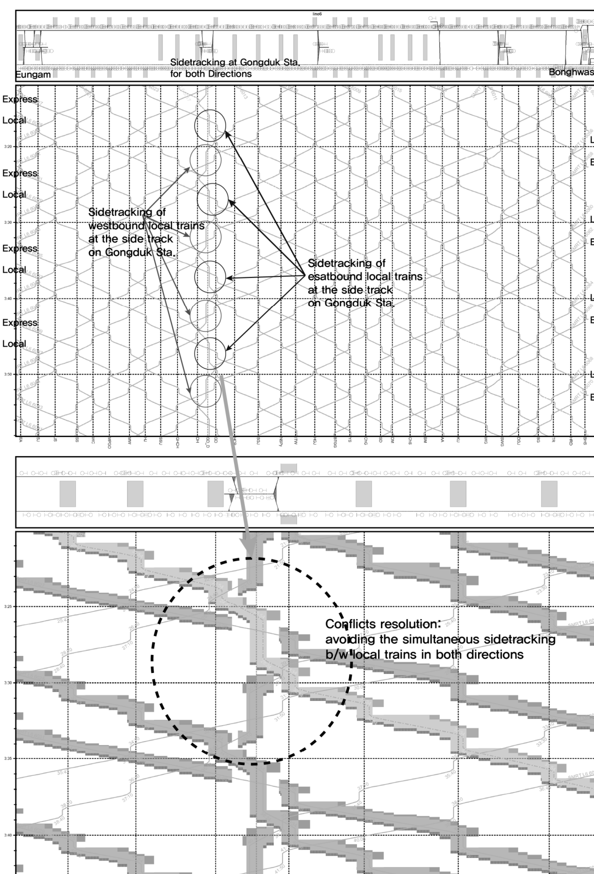

Fig. 16 Train schedule according to mixed traffic scenario 2

5. Conclusion and Further Study

To improve competitiveness of public transportation, need to introduce express trains in urban railroad is being raised. As most of Korean urban railroad lines are not built for operation of express trains, there is no sidetracking facilities and a huge amount of costs are required to install them as most lines consist of underground or overhead structures.

4) Number of operations and headway of local and express trains are the same as in scenario 1.

This paper has examined the possibility of mixed operation of local and express trains by using the existing overnight staying tracks of urban railroad. According to the result of adequate sidetracking time for local trains by using blocking time stairway model, it has been found that application of an uniform sidetracking time to all sidetracking stations is not appropriate as there is difference in sidetracking time for each location due to the difference in blocking length around those stations, etc. It is also necessary to examine the blocking time conflicts of all block sections including the sidetracking stations as well as stops before and after those stations in order to determine sidetracking time which ensures no conflict between trains.

As a case study, one to one mixed operation by using overnight staying tracks was examined for SMRT Line 6. This paper proposes a method to solve simultaneous sidetracking at Gongduk to Daeheung section of up and down local trains by switching the operation method of local/express trains at Eungam Station. A variety of scenario setting and analysis for mixed operation should be performed, however, to find an operation method suitable for the corresponding line and it is judged that the following limitations of this paper should be cleared by further study.

- Four blocking(five aspects) signal system was applied to the entire Line 6 but as speed code is different for each track circuit, detailed signal system should be reflected.
- This paper assumes that buffer time between trains is 30 sec but the application example in actual operation should be examined and reflected.
- Assumed parameters related to train operation such as route setting/clearing time, signal aspects check time, overlap setting and train traction power/braking force conditions.
- Feasibility of express train introduction should be ensured by examining the effect of train headway change or train operations change on train service level for passengers and profit of the operator.

Acknowledgement

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A Study on a Mountain Train Operation

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Keyword : Mountain train, operation, Bukhan Mountain

Abstract. Korean Peninsula spans 1,200kilometers north to south and 840 kilometerseastto west, and 75% of the territory is covered with mountainous terrain, but the strategy in implementing transportation infrastructure have been mainly focused on the road. It is a contrast to the recent trend in strategy of advanced countries which is to pursue their roles and mission by prioritizing railway infrastructure to their strategy, so they can have a sustainable development against global warming through adopting low-carbon transport and achieving green growth. Therefore, it is highly recommendable for us to change our strategy into the one with railway-oriented which include urban railway transit.

1. INTRODUCTION

1.1 Background and purpose of research

It is very sad that there is no mountain railway in Korea which is 70% of country covered by mountains. Korea is a peninsula with 1,200km north to south and 840km west to east. There are only high-speed train, express train, long-haul train, and subway for city as a railway infra.

Considering balance development of national land and railway infra system, mountain railway should consider environmental and geographical characteristic of nation. In this study, it assumed to consider problem and alterative of mountain railway in such as Dobongsan in the capital by technical level and tourism side of view.

1.2 Range and method of research

Consider tourism railway infra through Bukhansan which is the famous mountain in Seoul, the capital, for trafficking weak the elderly, the infirm, children, and handicapped to get close environmentally-friendly. Moreover suggests practicable studying method by analyzing using condition of Bukhansan by advanced cases and traffic condition, nature condition and related laws.

2. Mountain railway

2.1 Definition of mountain railway

Mountain railway refers to a safe and proper vehicle system constructed on the steep slope of mountainous areas for users' purpose.

2.2 Origin of mountain railway

Harz in Germany adopted it to mountain railway first in 1885 and Abt,R in Switzerland creates for climbing railways of

Switzerland and Germany in the end of 19 century. There are the gears rail that is installed in the center of track and the cog-wheel rail that makes the gears installed in engine locomotive and tram interlock to prevent slipping down in climbing up and down.

2.3 Classification of mountain railways

2.3.1 Operation type

1) Abt-system railway

Abt, R from Switzerland creates the system that carves racks on the thin steel plate and installed 2~3 rack rails in the center of railway track and interlock pinions together to move. It is adopted in Switzerland and Germany.

2) Switchback system railway

The train runs in zigzag in a steep hill and goes reverse direction when the train arrives at the end to increase height. It is often used in Japan.

3) Locher system railway

It is invented by E.Locher from Switzerland, has gear teeth cut in the sides engaged by two vertical pinions interlock on the two sides of train by using special rail that carved rack on both side of steel plate. It is used for more than 150% sharp steep area.

4) Strub system railway

It is invented by T Strub from Switzland, firstly used for Jungfrau railway in Switzland. The average grade is 25%, the shortest radius of curve is 100m. the machined rack teeth is installed in a train and the length of rail is approximately 100mm. Safety jaws is engaged with the underside of the head to prevent derailments.

5) Riggenbach system railway

It is invented by N.Riggenbach from Switzland,. Engage a ladder rack between two steel plates and interlock a pinion. It is used in Washington climbing railway.

6) Fell railway

It is invented by E.Fell from England. Install a general rack like the rack in the center and use sides for brake and stick to enhance the climbing ability. The power is weaker than rack rail but it is fast and convenient to install.

2.3.2 System type

1) Cable car type

The number of passenger is limited and it is used in the site of long length, sharp grade, and big height difference between track and the ground. It is operated continually or two carriages to use power effectively. Also the rescue method system is prepared for breakdown in down way.

2) Flexible gear type light subway

A grade is a quite steep with under 300‰. It is generally adopted to a long route with many curves. It is adopted to new route design.

3) A general steel wheel

A grade of light railway is gentle with under 80%. Itis often adopted to a long route with many curves.

4) A mountain monorail

It is used in the place that is short extension length, grade is steep with under 40%, and many curves. It is commonly constructed not far from ground to consider emergency escape.

5) Lift system

A grade is steep and using time is short. It is adopted for trains users with small family group.

2.4 Operation cases of mountain railway

2.4.1 Domestic case

1) A mountain monorail

It is operated in a short section, and its shortest curve is under 30m which causes small cost of construction. The sudden grade climbing ability is excellent and it is economical system due to using rubber railway same as monorail. It is used for a sightseeing in Hwaam cave in Jungsun in Gangwon-do, Deageumgul in Samchuk, Ttankkeut sightseeing in Haenam in Jeonnam, Ceorwon peace observatory in Gangwon-do.

2) Switch system(Zigzag type)

Use zigzag type of switchback system to overcome a grade, but it is dangerous when the train goes back ward which is a big problem in high-speed operation. The use of the system of 1.5km from Hongchun station~Nahanjeon station in Samchuk is reduced.

2.4.2 Overseas cases

1) The Jungfrau railway

It is a Strub type rail way that installs wide rack rail in the center of both rails and interlock pinion to the rack to move. It is firstly used for climbing rail way in 1898, and opened from Kleine Scheidegg to Jungfraujoch for 9.3km in 1912. It is a Strub type rail way that installs wide rack rail in the center of both rails and interlock pinion to the rack to move. The machined rack teeth is installed in a train and the length of rail is approximately 100mm. Safety jaws is engaged with the underside of the head to prevent derailments.

3,454m altitude, length 9.3km, the sharpest grade 250‰ (Speed in the sharpest grade : 14km/h, Average : 27km/h). the trains operated for 40 years takes big repair to re-use. The popular route is a Jungfraujoch railway from Kleine Scheidegg (2061m altitude) to Jungfraujoch(3454m altitude) for 12km. Passengers can see scenery in the first section in mountainous area, and after it passes a limestone tunnel(length 7122m).

2) The Hakone Mountain-Climbing Railroad Line in Japan

It is opened the only switch back type mountain train in 1919. It takes 55min from Odawara to Gora for 15km and takes 40min from Hakene-Yumoto to Gora. Altitude increases 1m(8%) by 12.5m and passes sharp curves in shortest 30m radius which is the only railway in the world. Water is sprayed to reduce friction between rails and train wheels in turning curves. It switches back three times.

3) Hakone Cable Car in Japan

It begins operation in 1920. Current cable car model begins to operate in 1995, with red and black colors. It runs 1.2km from Gora to Sounzan which is 214m altitude difference. The highest grade is 200/1000. The two cable cars can carry 250 passengers per time and it takes 10min from Gora to Sounzan.

4) Hakone ropeway in Japan

It takes 30min from Sounzan which is the end stop of Hakene ropeway to Togendai in Asinoko lake for 4,035m. it is the longest ropeway in Japan and second cable way in the world following Kriens railway

13 passenger limit gondola runs every minute and when it arrives at the highest point, it is at the 130m height from the ground.

5) Shizouka Mountain Railway in Japan

It operates by a diesel train up to certain grade and engaged to Abt system train from a sharp grade.Abt system is adopted for 1.5km out of 4.8km.

6) Koya-san Mountain Railway in Japan

It takes 1hour and 50min from Nanba station in Osaka by an express and 6-carriage train is operated in the city route and 2-carriage train is operated from Hasimoto station to Goyasan for sightseeing only.

The Goyasan mountain train takes passengers every 5min up to Goyasan basin(867m) by electric cable cars. It takes low grade with 289‰~563‰(approx. 45~50degree) compare with its operating length(0.8km) for safety of passengers. Also the passenger seats are designed as a stair.

The two trains operates together and they are changed in the middle of route by using shape rail.

7) TranzAlphine in New Zealand

It is opened with 223.8km route(4 hours 25min) with 16 tunnels and 5 bridges in 1940. It starts from Christchurch and passes Arthur’s Pass and Grey mouth that cross east to west of country. It takes less than 4hours from Christchurch in the east shore and cross the wide and rich Canterbury Plains and pass the huge Southern Alps mountains in New Zealand.

8) Peak Tramway in Hong Kong

It is the famous transportation in Hong Kong since 1888. And it is the fast vehicle to go up to the Victoria park. It runs up and down for 386m for 5 mins and shows fantastic view of Hong Kong island and Vitoria harbor, and Kowloon peninsula. The length is 1.4km and the sharpest grade is 48‰, two trains run up and down and 6 stops. 17,000 passengers take on the train daily(2007).

9) Alishan Forest Railway in Taiwan

It is one of the three mountain railway in the world. The route begins from the Zhushan station in 30m altitude to Alishan station in 2,216m altitude. The sharpest grade is 6.26%, and the shortest curve is 40m. It is a rear-wheel drive train. It goes around Dolishan 3 times and climb 200m from 5km point. It passes 50 tunnels and 77 bridges. It goes reverse at the Dependao by Z switchback. Visitors can enjoy forest, sea of clouds, sunrise and sunset on the railway. It runs 71.4km for 3 hours and 30 min, the average speed is 20km/h.

10) Colorado Springs in USA

Pikes Peak(14,110'approx.4700m),a cog-wheel narrow gauge railway which is one of the three mountain railway in the world. It goes straight up for 9 miles starts from 5671 feet to 9539 feet miles which is the highest point in the world. The first train is built in 1891 and it is still running for 107 years. The train starts from Manitou and goes up to the top. It is running from April to December.

3. Consideration of Bukhansan mountain railway

3.1 Background of consideration

A national park Bukhansan, 837m height, has many valleys and waterfalls and shows different beautiful sceneries in four season. More than 30milian people visit Bukhansan to improve their quality of life in well-being age by enjoying the fine scenery of the famous mountain in the capital. It is plant to develop the new transportation linked with a subway to get close to mountainous area environment-friendly for visitors include trafficking weak(the elderly, the infirm, the children, and handicapped) and for increase city's status as a sightseeing city by developing a sightseeing railway.

3.2 Use state of Bukhansan

Analyze number of visitors in Bukhansan, the national park based on data before free entrance act even though it is assumed that the number of visitors is increased 50% since the act was enforced in 2007.

Table 1. Status of bukhansan visitor number

	2010	2011	2012	2013
Number of guest	8,508,054	8,145,676	7,740,610	7,146,161
Averate daily guest	23,310	22,317	21,207	19,578

3.3 Traffic condition

Currently, resident of Ilsan and Eunpyeong in the west of Bukhansan must cross Bugak tunnel or go around Songchu and Uijeongbu to go to Sanggye and Ui-dong area. However they can reduce distance and travel time from Gupabal station line no.3 to Ssangmun station line no.4 by using the mountain railway. Therefore it reduces traffic congestion cost and increase economic income. Especially, it is convenient for trafficking weak who the elderly, the infirm, pregnant woman, and handicapped.

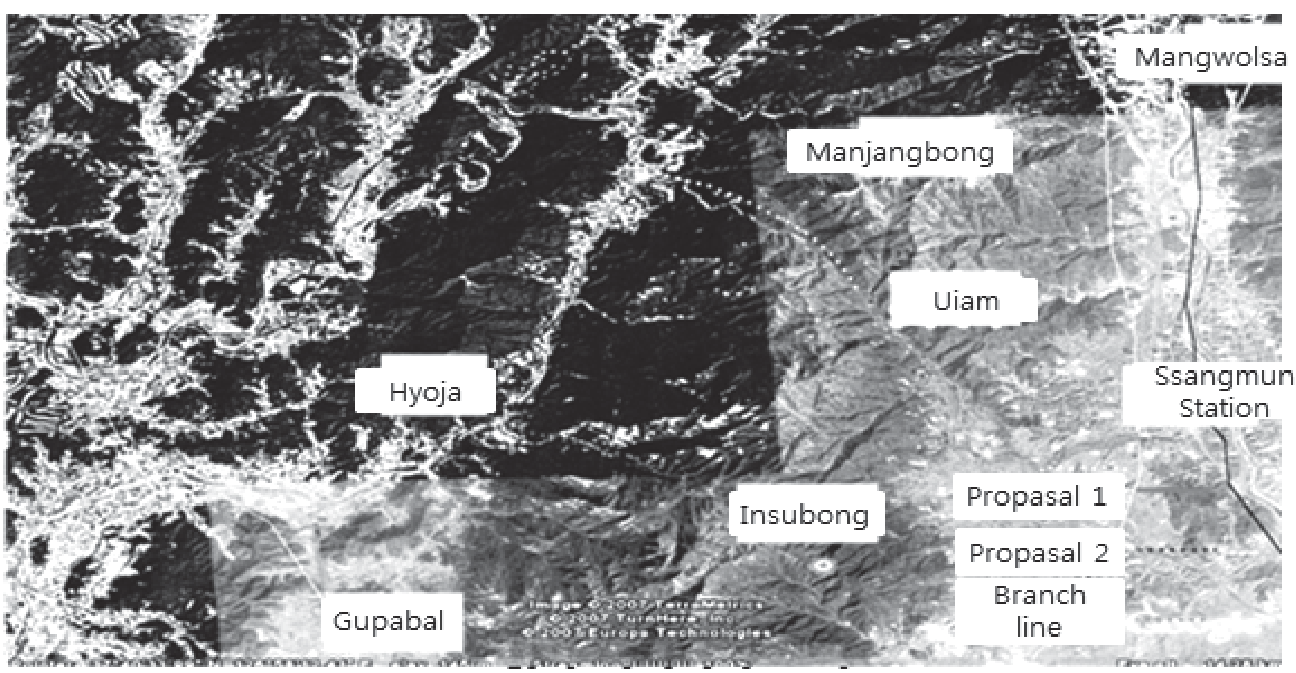

Fig. 1 Mountain train route

3.4 Problem

Cable and railway construction is possible under the natural part law but it is expected that a sharp conflict of agreed and disagreed people for the need of construction. Feasibility study and development of objective standard about cable and railway construction are necessary. Also it is expected that the aggressive opposition of environment group. Development of project is decided through an authoritative interpretation of questions of ministry of construction and transportation under urban railroad act, and cableway railroad act about route and system ect.

The construction cannot use current railway system due to passing city and mountainous area together. Also the separate end stop and garage is necessary for maintenance and parking trains.

3.5 Consideration of route

Consider two ideas of the analysis of route independently.

(1st idea)

Gupabal Station~Eunpyeong new town~Hyoja Maeul~Sagimack-gol~Emja Maeul~Uidong~Duksung Women's University~Ssangmun Station(approx. 18.7㎞)

(2nd idea)

Gupabal Station~Eunpyeong new town~Bukhansan mountain cabin~Uidong~Duksung Women's University~Ssangmun Station (approx. 14.0㎞)

3.5.1 Consideration of facilities of route

(1st idea)

Gupabal~Hyoja(4.0km) Ui~Ssangmun Station(3.8km) AGT light railway, Hyoja~Umja Maeul~Ui(10.9km) Cable way

(2nd idea)

Gupabal~Bukhansan mountain cabin(4.5km) Ui~Ssangmun Station(3.8km) AGT light railway, Bukhansan mountain cabin~Ui(5.7km) : Cable way

3.5.2 Conceptual estimation(except the land acquisition cost)

Table 2. Approximate cost

Item	Urban route (AGT)	Mountain route (Cableway)	Total	Remark
1	3,292	1,145	4,437	AGT:7.8km Cableway:10.9km
2	3,503	599	4,102	AGT:8.3km Cableway:5.7km

3.5.3 B/C Analysis(1st item)

Table 3. Approximate cost [Unit : hundred thousand won]

Item	Amount	
Cost	Construction	473,776
	Vehicle	32,720
	Operation	482,430 (30years)
	Total cost	1,083,891
	Total cost discount	633,073
Benefit	Travel time reduction	19,060
	Car operation reduction	43,729
	Car accident reduction	2,486
	Environmental expense reduction	1,088
	Residual value	93,677
	Tourist	1,412,325
	Total benefit	1,588,156
	Total benefit discount	509,398
B/C		0.8

3.5.4 Review related law

1) Natural park law

A) Regulation of type of facility construction in natural part.

(a) Change of park construction plan and deliberation of park commission

(2) Conduct natural environmental impact assessment examination when change park construction plan(Article no. 2 of no. 17 Act)

B) Effects evaluation law related to environment, traffic, and disaster

(1) Cable way over 2Km : Environmental effects evaluation is necessary before obtaining permission to conduct construction

(2) Cable way under 2Km : pre-environmental evaluation negotiation is necessary when change the form and quality of land for more than 5000㎡(nature protection district)~ 7500㎡(nature environment district)

C) A law of cable way and railroad

(1) Cable way business : the business that transport people or freight by a carriage connected to a rope hanging in the air.

(2) Railroad business : the business that transport people or freight by rail tracks on the ground

D) the Cultural Properties Protection law

(1) The cultural properties protection law applies priority in case of natural park overlapping Natural Reserve, natural monument, scenic spot and ect.

4. Conclusion

Plan to use general public transportation (bus) for city area and use the new transportation(cable) only for mountainous area and linked them in a single-system.

- 1st idea is expected not many people use compare to construction cost and also it spends over running time due to long mountain track
- 2nd idea is also expected not many people use compare to construction cost, but it can bring more visitors if construct a huge recreational facilities in the Insubong Peak

As a result of B/C analysis, the result of 1st plan is 0.8. Cost and convenience of the economic validity can be changed by social condition. The visitor's willingness to pay of Bukhansan mountain railway can be increased constantly if the tour environment is improved by relation to Bukhansan tourism, sightseeing facilities near other stations of the route

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A study of selecting components for Condition-Based Maintenance through failure data analysis of railway vehicles

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Keyword : CBM (Condition-Based Maintenance)

Abstract. Railway vehicles is composed of mechanical, electrical, electronic, communication, and a variety of systems, failure and also shows a variety of forms. many of the parts are repaired or re-use, is difficult to consider the public interest, such as the safety of the train station and passenger service .
Recently "all of the equipment is not to increase the failure rate over time, but failures is often occur at random, regardless of the time" because it is established theory is that in developed railway companies overseas, I have applied the Condition-Based Maintenance(CBM) that know the need for changes in the maintenance system through monitoring the state of the machine and equipment.
SMRT is trying to be based on Condition-Based Maintenance(CBM) doing train failure data analysis and risk analysis of target component selection to match to these changes.

1. INTRODUCTION

Maintenance has undergone lots of changes. Such changes are attributed to diversification and increase in physical assets which require maintenance, complicated design, new maintenance technology, a chance in viewpoint of organization and responsibility of maintenance.

Maintenance in the field of domestic rapid transit has been performed in the same cycle and inspection method even though times have changed and new technologies have been introduced. It is high time to review system for effective maintenance. SMRT studies by selecting components that allow rolling stocks condition to be diagnosed and malfunction of rolling stocks to be predicted by collecting and using reliable data, coping with a change in maintenance system and participating in「development of condition based SMRT maintenance core technology」 project of land and transport R&D.

2. Body

2.1 What is condition based maintenance (CBM) ?

CBM can improve efficiency of components by conducting an inspection on a regular basis which makes it possible for unnecessary maintenance to be avoided. During accidental fault, times and causes of failures are various and it is difficult to understand occurrence of failure statistically and therefore preventive maintenance is meaningless. During accidental fault, measuring temperature, vibration and frequency by diagnosing condition of equipment helps to find optimum time and way of preventive maintenance. Performing maintenance before failure occurs by accurately predicting remaining life of equipment based on information about condition of equipment helps to improve MTTR(Mean Time To Failure) and minimize expense and workers that are required to perform maintenance. Reliability modeling that aims to track performance parameter and predict when maintenance is required accurately is essential.

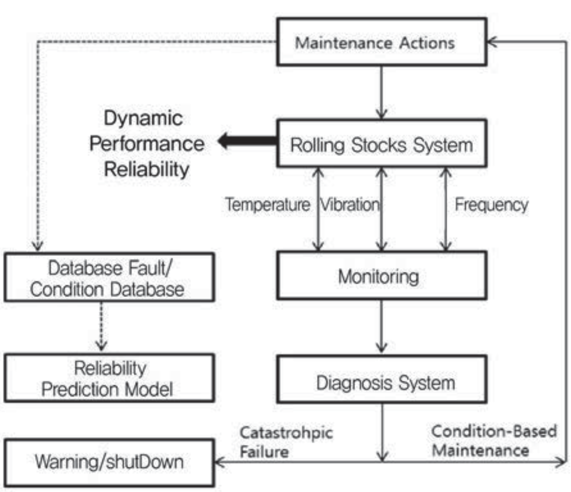

Figure 1. CBM conceptual diagram

Predicting when maintenance is required accurately based on reliability modeling about remaining life is important so that optimum preventive maintenance can be found. Accumulating reliable data is necessary so that preventive maintenance work and history of equipment can be tracked by using preventive maintenance work data which are inputted on a daily basis. Indicators of RCM activities which are produced by conducting aforementioned activities are used to evaluate reliability, maintainability, availability, safety of applicable system and a result of analysis is notified to a relevant field so that the field can prepare measures.

2.2 Actual status of condition based maintenance(CBM)

In aviation field, a result of real time condition based maintenance is used to improve efficiency of operation. Life management that reflects operation environment has been applied to main aircrafts (F-15K,F-16,T-50 etc.) of Korean Air Force. A program that evaluates useful life of F-16 and manages life by analyzing fatigue life and operation of each aircraft based on actual flight data has been used.

In steam-power generation field, predictive diagnosis that aims to secure reliability of equipment so that power can be supplied in a stable manner was established early .

Alstom based in France and Simmens based in Germany and London Underground applied CBM to electric train in order to improve reliability of rolling stocks and reduce maintenance resources and expansion of heavy maintenance cycle. In Korea, it is necessary to develop condition based maintenance (CBM) core technology because there are frequent failure of rolling stocks as running of rolling stocks has increased. It is necessary that competitiveness of rapid transit rolling stocks should be improved by introducing new SMRT maintenance system and developing core technology because Korean rolling stocks industry has a difficulty in advancing into overseas market due to low reliability and the lack of maintenance core technology.

2.3 Relations between CBM and RCM

Railway related regulations and railway total safety audit recommend applying reliability technique to electric train maintenance system. Efficiency of maintenance/operation should be improved . CBM is performed based on RCM analysis, implementation and process. Therefore, relation between RCM as process to decide the most effective maintenance strategy, method that implements selected maintenance approaches and CBM which is source of technology should be established .

SMRT will perform analysis by establishing RCM process as follows based on experience of maintenance and computation system operation.

1) Selecting system and collecting information : Collect basic information on selected equipment to be analyzed.
2) Defining system boundary :Define main devices of selected system according to functions.
3) Preparing system description and functional block diagram : Prepare description and functional block diagram of applicable system .
4) Defining system function and failure : Define function and failure of devices .
5) Analyzing failure mode and effect : Analyze failure mode of devices and effect by failure.
6) Analyzing decision logic : Analyze critical condition of failure based on decision logic analysis sequence.
7) Selecting maintenance work : Select what inspections (e.g. periodical inspection, condition inspection or post inspection) are used to conduct maintenance by sequence

Such procedure is to prevent and repair failure of components and to maintain functions by measuring importance of components in function to adopt optimum maintenance. This study will predict remaining life of devices/components based on prediction of failure by finding types and reasons of failure based on analysis of sensor and data in order to guarantee required system performance by applying CBM to important components

2.4 Procedures for selecting main components of SMRT for condition based maintenance (CBM)

This study analyzed information on failure of 208devices in electric train that runs subway line no 7 which SMRT operates based on data on failure that were collected from 2001 till 2011 and corrected erroneous data while analyzing data. Frequency of failure by devices is as follows.

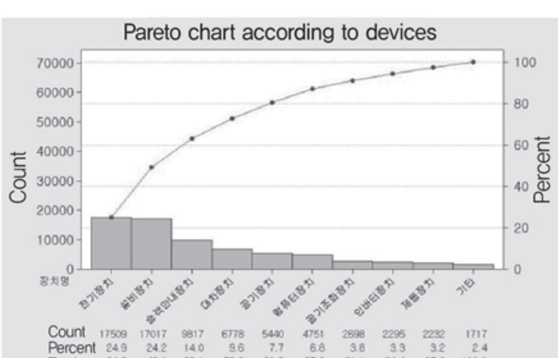

Figure 2. frequency of failure by devices

It has been found that in electric system, many failures are related to devices and in equipment case, lots of failures are related to side door for passengers. In passenger guide device, there are many failures in passenger room indication device and announcement system. It has been found that lots of failures in devices are related to passenger service which do not interfere with operation of electric train significantly. Failure which is related to computer, inverter and brake is remarkably low.

Main devices were selected by considering severity which influences operation based on frequency of failure. Hazard analysis matrix which is used by SMRT was utilized as standard for analyzing hazard and details are as follows. Hazards were classified into A,B, and C. Element that may cause hazard during operation should be identified and reduced or removed by analyzing hazards. Severity should be classified considering safety, customer service etc. Table below shows effects that have train service .

1) Fatality : Fatality includes those who died on the spot and those who died within 72 hours after getting injured
2) Major injury : Major injury includes those who suffer an injury that requires over 3 weeks of hospitalization or those who lose a part of body or function permanently
3) Minor injury : Minor injury includes those who suffer an injury that requires treatment for up to three weeks

Item	Class	C1	C2	C3	C4	C5
		Marginal	Serious	Critical	Catastrophic	Disastrous
Service	Disruption to line service	〈10 mins	〉10 mins 〈1 hour	〉1 hour 〈8 hours	〉8 hours 〈 1 day	〉1day
Safety	Fatality	0	0	0	1	〉2
	Major injury	0	0	〉1		
	Minor injury	0	〉1			

Figure 3. Severity class

Occurrence frequency of failure was classified based on failure data which occurred actually.

Level		Range
F5	Frequent	More than 10 times per year
F4	Probable	Once to 10 times per year
F3	Occasional	Once every 1 to 10 years
F2	Remote	Once every 10 to 100 years
F1	Improbable	Less than once every 100 years

Figure 4. Occurrence frequency class

Frequency \ Severity		C1 Marginal	C2 Seriuos	C3 Critical	C4 mortal	C5 Disastrous
F5	Frequent	B	A	A	A	A
F4	Probable	B	B	A	A	A
F3	Occasional	C	B	B	A	A
F2	Remote	C	C	B	B	A
F1	Improbable	C	C	C	B	A

Class	Matrix Definition	Actions
A	Unacceptable	Unacceptable Source Of Hazard And Must Be Removed
B	Tolerable	Acceptable If There Is Proper Control And Consent
C	Broadly Acceptable	Acceptable Without Any Consent

Figure 5.Hazard matrix

2.4 Selecting main components of SMRT for condition based maintenance (CBM)

SMRT conducted analysis of hazard for main devices based on field data on failure in subway line no 7 and a result of analysis is as follows.

○ Order of priority in failure of high voltage equipmenr

Ranking	Line Label	Frequency Of Occurance	Severity	Hazard	Note
1	Hscb Assy	F5	C1	B	Leakage Of Air In Electric Converter
2	Slider	F5	C1	B	Deformation Of Slide
3	Cck	F4	C1	B	Leakage Of Air In Electric Converter
4	Bellows	F4	C1	B	Damage Of Bellows
5	Cck(Atp Contactor)	F4	C1	B	Damage Of Contactor
6	Pantograph Support Insulator	F4	C1	B	Damage Of Insulator
7	Pressure Converter	F4	C1	B	Air Leakage
8	Braided Wire Assy	F4	C1	B	Breakage Of Braided Wire
9	Main Spring Assy	F4	C1	B	Poor Spring Pressure
10	Dc Arrestor	F4	C1	B	Poor Resistance

○ Order of priority in failure of equipment − side door for passengers

Ranking	Item	Frequency Of Occurance	Severity	Hazard
1	Dooe Engine Assy	F5	C1	B
2	Electronic Converter Assy	F5	C1	B
3	Push Rod Switch	F5	C1	B
4	Upper Rail	F5	C1	B
5	Other Accessories	F5	C1	B
6	Door Switch Assy	F5	C1	B
7	Rubber	F5	C1	B
8	Lower Rail	F4	C1	B

○ Order of priority in failure of brake

Ranking	Item	Frequency Of Occurance	Severity	Hazard
1	Electric Pneumatic Change Relay Valve(Epr2A)	F5	C1	B
2	Service Brake Electronic Valve(Sbv)	F5	C1	B
3	Pressure Reducing Valve	F5	C1	B
4	Pressure Sensor Unit	F5	C1	B

Ranking	Item	Frequency Of Occurance	Severity	Hazard
5	Epv(Epl Electric Pneumatic Change Valve)	F5	C1	B
6	Ecu	F5	C1	B
7	Emergency Brake Electronic Valve(Ebv)	F5	C1	B
8	Electric Contact Insulating Cork (Ascs1, Bccs1)	F5	C1	B

○ Order of priority in failure of driving device

Ranking	Line Label	Frequency Of Occurance	Severity	Hazard	Note
1	Gear Box	F5	C1	B	Breakage of Gear Box
2	Drain Plug	F4	C1	B	Wearing By Regular Oil Exchange
3	Gear Coupling Spring	F4	C2	B	Breakage of Spring
4	Oil Level Gauge O-Ring	F4	C1	B	Oil Leakage of Oil Level Gauge
5	Other Accessories	F4	C1	B	
6	Axle Bearing Housing	F4	C2	B	Oil Leakage
7	Oil Level Gauge	F4	C1	B	Damage of Oil Level Gauge/Oil Leakage
8	Breather	F4	C1	C	Damage of Breather
9	Tm Speed Sensor Assy	F3	C2	B	Poor Communication

○ Order of priority in failure of bogie device

Ranking	Line Label	Frequency Of Occurance	Severity	Hazard	Note
1	Ground Brush	F5	C1	B	Breakage Of Ground Brush
2	Safety Hanger	F5	C1	B	Breakage Of Safety Hanger By Vibration
3	Lateral Damper	F5	C1	B	Oil Leakage By Damage Of Seal
4	Speed Sensor	F5	C1	B	Breakage Of Connector That Connects Speed Sensor
5	Levelling Valve	F5	C1	B	Leakage Of Air In Valve
6	Journal Box Assy	F5	C1	B	Breakage Of Ground Brush Spring
7	Wheel	F4	C1	B	Damage Of Wheel
8	Bogie Piping	F4	C1	B	Leakage of air

When analyzing hazards of five devices, it was found that class B is related to high frequency rather than high severity and air leakage and oil leakage account for a great part of failures and therefore severity is low. Hazard was determined by considering severity and occurrence frequency of each device. SMRT established a criteria for selecting components for condition based maintenance (CBM) based on aforementioned result as follows.

1) Devices that influence train service such as delay, replacement of rolling stocks and relief wrecking drive
2) Devices that are difficult to repair and supply of materials is not easy
3) Devices that monitoring is possible and are not consumable goods

Table 1. Components for CBM

<table>
<tr><th>Classification</th><th>Components for CBM</th><th>Note</th></tr>
<tr><td>Inverter unit</td><td>Control unit, ARM UNIT, OVT UNIT</td><td rowspan="5">Components for CBM are subject to change depending on circumstances</td></tr>
<tr><td>Break gear</td><td>Electric pneumatic change relay valve, main air compressor, CMSB inverter</td></tr>
<tr><td>Driving device</td><td>Gear box, Wheel</td></tr>
<tr><td>Slide door for passengers</td><td>Door cylinder electronic converter</td></tr>
<tr><td>High voltage equipment</td><td>HSCB(main circuit breaker)</td></tr>
</table>

Reliability analysis will be conducted by using ten types of components and suitability for application of CBM will be verified based on a result analyzed. RCM process will be conducted so that remaining life can be predicted based on analysis of sensor and data in order to guarantee system performance and find reason of failure by applying CBM to selected ten types of component.

3. Conclusion

As rapid transit rolling stocks have increased and there have been lots of failures of rolling stocks, the need to perform Condition Based Maintenance(CBM) for core components to decrease failure has risen. Operator tries to improve maintenance system through RCM and apply CBM to main components that may cause disruption of service or accidents and predict when components should be replaced or maintained considering conditions of components and prevent failure.

Components for CBM among main devices of electric train which runs subway line no. 7 were selected to conduct analysis of reliability of selected 10 types of components in order to provide useful data for establishing maintenance method which CBM is combined with existing maintenance system that can maximize availability.

Postscript

This paper was conducted as a part of study of condition based SMRT maintenance core technology development(task number : 13RTRP-C068243-01) implemented by Korea Agency for Infrastructure Technology Advancement.

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