Improvement Measures for Railway Station Parking Lots Based on Universal Design

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Abstract: Current railway station parking lots fail to take consideration of the characteristics of transit users, including the disabled. Thus, these parking lots contain many problems regarding safety and convenience. This study aims to present improvement measures for such parking lots in order to enhance their safety and convenience by analyzing parking type, parking width, and vehicle flow. As a result of safety analysis regarding parking type, 60°angled parking showed a 40% decrease in parking time compared to a 90°angled parking. Moreover, the number of times that vehicles reversed was decreased by 38.4%. An actual vehicle test result showed that the appropriate parking width is 2.7meters. Furthermore, analysis reflected that the safety of a railway station parking lot increases when the parking lot entrance and exit are separated into one-way traffic. In order to acquire the safety of transit users, the separation of pedestrian and vehicle flow along with an installation of pedestrian pathways is necessary.

Keywords: Universal Design, Parking Type, Parking Width, Pedestrian Space

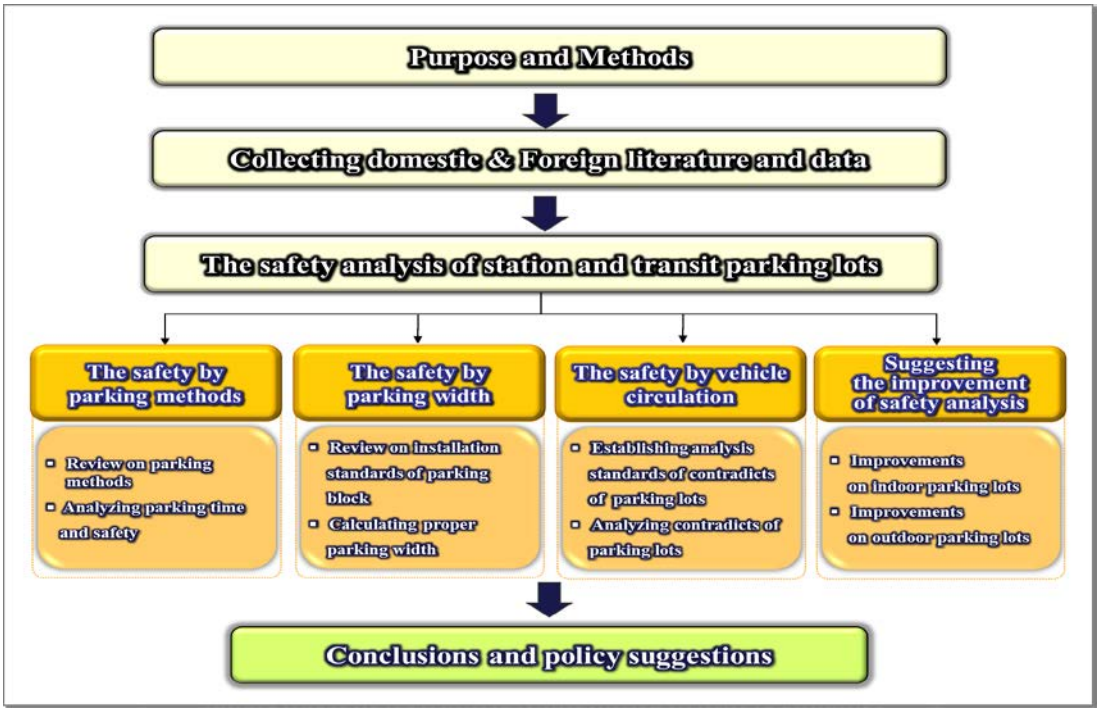
1. INTRODUCTION

1.1 Background and purpose

In recent years, the construction of convenient transit systems focused on the railway has been actively promoted. This is provided for the purpose of expanding the range of train transportation services that we offer, which had been limited to stations and trains, to traffic link transfer points. The Korea Transport Institute conducted a national survey on passenger accessibility of transportation facilities (March 2012) commissioned by the Ministry of Land, Transport and Maritime Affairs. According to the results of this study, in the case of the railways, about 23% of all passengers came to the railway station using a vehicle. Despite the increase in demand for commuting by vehicle, station and transit parking lots are being operated without clear legal regulatory and consideration of the characteristics of rail passengers. This poses many problems for safety and convenience. Recently, during the past three years, about 85% of the accidents that occurred in the parking lot happened in walkways and parking stalls. In addition, most have been shown to occur during the process of parking. It was found that this is generated by a lot of external factors aside from their own carelessness. In the case of the accidents involving cars in the parking lot, the width of individual parking stalls had the highest effect on the accident. Also, in case of accidents involving vehicle versus other vehicles, the vehicle flow has the highest effect on these accidents. Therefore, the improvement for the width of the parking stall and the vehicle flow is most urgent. The purpose of this study is to establish a plan to improve the safety and efficiency of passengers transferring to the railway station after parking a vehicle and leaving the parking lot.

1.2 Range and Method

Targets of this study included the transit stations and car lots operated by the Korea Railroad Corporation. First, after examining how many hours that rail passengers park their vehicles at the parking lot and the number of times they reverse their vehicles, we analyzed the advantages and disadvantages of by the parking type. Second, we reviewed the criteria for the parking width and calculated an appropriate parking lot width. Third, we predicted the risks of accidents during vehicle flow in the parking lot using a traffic conflict technique. Finally, we suggested an improvement plan for the prevention of parking-related accidents.



Figures 1. Research flow chart

2. LITERATURE REVIEW

2.1 Review on installation standards of parking stalls

Under Article 2 of Parking Lot Act, “Parking block” is defined as the entire stall of one or more parking unit block. The parking unit block means a stall that can be parked as one. The parking unit block is composed of parking length and width. A specification of the current parking unit stall is the same as <Table 1>, and is classified into parallel parking type and non-parallel parking type.

Table 1. Parking stalls of parking lots

Category		Parking unit block	
		Width	Length
Parallel type	Small vehicle type	More than 1.7m	More than 4.5m
	Medium sized vehicle type	More than 2.0m	More than 6.0m
	Residential areas(road without sidewalk)	More than 2.0m	More than 5.0m
Other types	Small vehicle type	More than 2.0m	More than 3.6m
	Medium sized vehicle type	More than 2.3m	More than 5.0m
	Large vehicle type	More than 2.5m	More than 5.1m
	Handicapped	More than 3.3m	More than 5.0m

Source : Parking stalls of parking lots under article 3 of parking lot act

Parking format is classified as parallel parking, perpendicular parking, 60° facing parking, 45° facing parking, and cross parking. Also, under Article 2 of Implementing Regulations in Parking Lot Act, a crossroad width is defined as parallel parking of 3.0m, right angle parking of 6.0m, 60° facing parking of 4.0m, 45° facing parking of 3.5m, and cross parking of 3.5m. In December 1990, the parking unit block of General Parking Type was reduced from a width of 2.5m, a length of 5.5m to a width of 2.3m, and a length of 5.0m. At that time, because more than 3,000cc vehicles were full width at 1.75m and full length at 5m, they were applicable to the current parking unit blocks (2.3×5.5m). But, since 1998, full width and full length of medium and large sized vehicles increased in comparison to past vehicles.

Table 2. Width by parking types

Category	Width	Category	Width
Parallel type	3.0m	45° Facing Type	3.5m
Right angle type	6.0m	Cross Type	3.5m
60° facing type	4.0m	-	-

Source : The structure and equipment standards of attached parking lots under article 11 of parking lot act

In addition, according to the same parking unit block that is applied to the station and the transfer parking, the safety and convenience for railroad guests are lowered.

Table 3. Change of parking stalls' dimension by year

Year	Standard type(m)	Parallel type(m)	Remarks
1971.12	2.5×6.0	2.5×7.5	3.5m
1988.02	2.5×5.5	2.5×7.0	3.5m
1990.12	2.3×5.0	2.3×6.5	Efficient use of parking lot(Article 3)
1995.08	2.3×5.0	2.3×6.0	Road without sidewalk : 2.0×5.0
2004.02	2.3×5.0, Small sized(2.0×3.5)	2.0×6.0	Road without sidewalk : 2.0×5.0, Small sized(1.7×4.5)

2.2 A study for the improvements of domestic parking unit blocks

In 2006, the Korea Ministry of Construction and Transportation conducted a study for improvements about standards coordinating of parking unit blocks and a crossroad regulation.

1) The improvement of parking unit blocks (1)

The gaps between vehicles in the parking lot should be at least 60cm in spacing, if there's no discomfort when getting in and out of the car. Parking blocks, except for the sections for the disabled and small vehicles was adjusted upward to match reality.

Table 4. Improvement of parking unit block (1)

Category	Current		Improved	
Parking type	Medium	2.3m×5.0m	Medium	2.5m×5.1m
	Small	2.0m×3.5m	Small	2.0m×3.5m
	Handicapped	3.3m×5.0m	Handicapped	3.3m×5.0m

2) The improvement of parking unit block (2)

General Parking type is divided into four types (Handicapped, small cars, small and medium-sized cars, and large cars) from three types (Handicapped, small cars, general vehicles). A small and medium-sized car has been applied to the existing General Parking section size. The improvement which established sections for big cars was suggested. New large car sections will be established by large vehicle parking blocks of 20% of the total surface parking, as the proportion for domestic large cars accounted for 20.1% as of the end

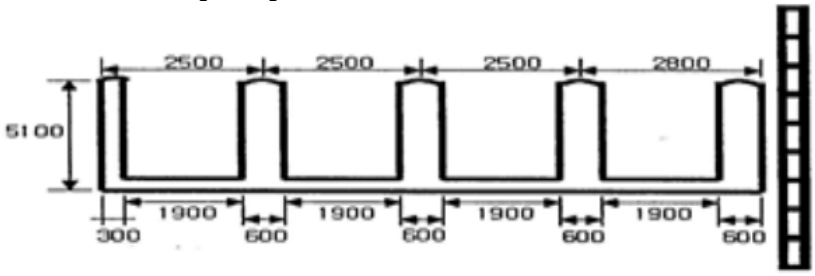
of 2005. However, applying to uniformly establish large parking section requires a great deal of parking policies. Therefore, considering the region and usage status, it was applied autonomously by less than 20%.

Table 5. Improvement of parking unit block (2)

Category	Current		Improved		Proportion
Standard parking type	Standard	2.3m×5.0m	Medium	2.5m×5.1m	20%
			Small & Medium	2.3m×5.1m	71-73%
	Small	2.0m×3.5m	Small	2.0m×3.5m	5%
	Handicapped	3.3m×5.0m	Handicapped	3.3m×5.0m	2-4%

3) The improvement of parking unit blocks (3)
When a large car parking zone is established in an existing parking lot, one of the two methods can be selected. Large car parking zones are being established in the existing parking lot. Also, the measure is recognized to the number of parking as much as reduced parking space. In other words, the regulation of light vehicle parking stalls is 2m×3.5m, but actually, 3m×5m was installed. The improvement plan will install the light vehicle parking at 2m×3.5m following the regulation, and utilize the gained area to install large car parking areas.

4) The improvement of parking unit blocks (4)
Even though the new parking block of large vehicles is established, if the vehicle is parked closer to one side, there is no point in adding new segments to the large car parking area. Accordingly, as of the end of 2005, the average width of the vehicles was about 1.8m~1.83m and the vehicles are not nearly over the entire width of 1.9m, along with large vehicles. A U-shaped parking block installation plan was presented with a middle width of 1.9m and a side thickness of 300mm. If a U-shaped parking block is enabled, and while maintaining the existing parking stall size, it raises the effect of the parking sections. Also, this has an effect on the driver's comfort and helps to prevent accidents.



Figures 2. Dimension of parking block

2.3 The design criteria of attached parking lots in the US
Parking systems in the United States have parallel, 30°, 45°, 60° and perpendicular parking. Parking specification is 2.7m×5.5m(14.9m^2) regardless of the parking system. Parking methods in the United States are the same as parking methods of South Korea except for the 30° parking scheme. The width of the parking lot in the United States is wider than in Korea, probably because the parking environment in the United States is more advantageous than in Korea and United States vehicles are bigger in size than Korean ones. Parking methods in the United States are subdivided into four types, and the parking width is wider in comparison with Korea. This is because the land area and vehicle sizes of the United States are large. But now, medium and large vehicles in Korea are growing, and the current parking width is low in safety and convenience level from the user’s point of view.

Table 6. Width by parking types (US)

Category by parking type	Width(m)
30° facing type	3.0
45° facing type	3.6
60° facing type	4.9
Right angle type	7.9

Table 7. Comparison of parking area and parking width in US and Korea

Nation	Parking area	Width of parking lot
US	100%	100%
Korea	about 80%	about 80%

2.4 The design criteria of Japan's attached parking lots

The Dimension of the parking stalls are applied to at least be higher than proposed in the <Table 8> according to the target vehicle. The margin of the front-rear direction is generally secured at about 0.3m. The opening and closing margin of the car door is secured to 0.5m~0.8m. Light vehicles and general cars are increased to the 0.5m~0.6m in length and the 0.3m~0.4m in width. In the case of vans, levels increased to 1m and 0.8m, respectively, determined by the Dimension of the parking lot. According to Article 17 of Tokyo parking regulations, a scale per more than 3/10 of the parking facilities which are located inside the building or on building grounds can be more than 2.5m in width and 6m in length. Among them, more than one is over 3.5m in width and 6m in length as parking facilities for the disabled.

Table 8. Dimension of parking blocks in Japan

Vehicle	Length(m)	Width(m)
Light-weight car	3.6	2.0
Small car	5.0	2.3
Common car	6.0	2.5
Small truck	7.7	3.0
Large truck and bus	13.0	3.3

The width of the Aisle where backward rotation for parking occurs is required to have a minimum value as shown on the left in <Table 9>. However, due to space limitations, if unable to do that, it can be reduced to the levels shown on the right. Parking systems in Japan generally have a lot of consideration of the convenience to a user. Also, the width and length of a certain area (30%) are higher than the reference value. This is in consideration of the convenience to the user. In addition, by comparison with Korea, it has the parking block regulation for buses and vans.

Table 9. Aisle width of parking block in Japan

Vehicle	Recommended value		Minimum value	
	Without sidewalk	With sidewalk	Without sidewalk	With sidewalk
Light-weight car	7.0m	6.5m	5.5m	5.5m(Two-way) 5.0m(One-way)
Small car				
Common car				
Small truck	7.5m	7.0m	6.5m	6.0m
Large truck and bus	13.0m	12.5m	11.5m	11.0m

3. SAFETY ANALYSIS BY PARKING METHODS

3.1 Parking method and arrangement of parking blocks

Parking methods are divided into parking method and arrangement of parking blocks. Parking methods involve forward parking and a reverse parking. In addition, the arrangement of the parking block can be classified as parallel parking and angle parking. Forward parking is a way to go into a parking block and leave a parking block through driving backwards. So parking is easy, but it takes some time to come out and it possesses risks as it doesn't ensure view of the road. Reverse parking is a parking method where the car first stops and then backs up, with the front of the car body facing the road. Going into a parking block takes some time. But it possesses the advantage of being able to park right away. Placement of parking block can be classified as parallel parking and angle parking. Parallel parking is parallel to cars parked on one side or both sides of the moving direction of the car. Angle parking is an angle with the direction of movement of the car.

3.2 Parking time and safety analysis by to parking methods

Parking time and safety analysis of parking methods are analyzed by examining the number of parking time and reverse parking methods according to reverse parking and transit users. Also, to compare the advantages and disadvantages based on the analysis of the parking method and to present applicable methods.

1) The method of safety analysis according to parking methods

To analyze parking time and safety in accordance with parking methods, the effect of parking to the target right angle parking and 60° angled parking is divided into two cases as follows and then subjected to analysis by a hypothesis test.

- Case Ⅰ: right angle parking versus 60° angled parking times
- Case Ⅱ: right angle parking versus number of reversals from 60° angled parking

Case Ⅰ sets the hypothesis to analyze the parking time affected by the parking time in accordance with the parking method. Case II is hypothesized identify any safety problems and difficulties in the parking method for the driver, through examining whether the parking method increases the number of reversals during parking.

Table 10. Hypothesis established in each case

Category	Hypothesis
Case Ⅰ	▪ H_0 : The parking time of right angle parking is shorter than that of 60° parking ▪ H_A : The parking time of right angle parking is not shorter than that of 60° parking
Case Ⅱ	▪ H_0 : The amount of reversing for right angle parking is less than that of 60° parking when parking the car ▪ H_A : The amount of reversing for right angle parking is not fewer than that of 60° parking when parking the car

2) Collecting data to analyze safety

We collected data with a variable number of parking time and number in the parking lot which has been installed at right angle parking and 60° angle parking in order to analyze the impact of parking method. Research method was to film target rail passengers using stations and transit parking lots during the day and to analyze parking time and number of each parking method.

Table 11. Parking time by parking types

Category		# of Sample	Parking time(Seconds)			
			Mean	Standard Deviation	Minimum	Maximum
Case Ⅰ	Right angle parking	600	24.02	6.29	9.6	39.1
	60° parking	600	14.18	5.64	7.8	31.2

Table 12. Parking number by parking types

Category		# of Sample	Parking time(Times)			
			Mean	Standard Deviation	Minimum	Maximum
Case Ⅱ	Right angle parking	600	2.28	0.77	1	4
	60° parking	600	1.40	0.49	1	2

3) Hypothesis verification

The hypothesis is a hypothetical description of the population, which is called a hypothesis test of these hypotheses to determine what is right and wrong. Using a sample derived from the population to make a decision about a population is called the statistical decision, and one should establish such a statistical decision as a theory first. In general, a hypothesis set in order to be dismissed by a counter argument; this kind of hypothesis is called the null hypothesis or the zero hypotheses. We tried to learn the time and number of parking in order to prove that 60° parking is the most efficient and safe than a right angle parking and to test the difference between the two methods. Therefore, the null hypotheses are set "A right angle parking involves shorter parking time" and "A right angle parking has fewer reversals". The hypothesis is the null hypothesis value obtained from the sample under the assumption that, indeed, the time value will be larger or smaller than the threshold value determined under the significance level, and the adoption or rejection of the null hypothesis.

To test the difference between the 60° angle parking and right angle parking, and to test the hypothesis using the test because we didn't know the distribution of the two populations. The size from the two regular populations $N(\mu_1, \sigma_1^2), N(\mu_2, \sigma_2^2)$, with unknown population variance is n_1, n_2. And when variance of two populations are assumed not to be same, the difference with the sample mean, which is the estimated amount regarding the difference of the population mean $\mu_1 - \mu_2$, and will follow a t-distribution using the estimator s_p. In this case, when the H_0 is true, equation (1) is used to the test statistic. Through this, the critical value can be found by following:

$$T = \frac{(\bar{X} - \bar{Y})}{s_p \sqrt{\frac{1}{n_1} - \frac{1}{n_2}}} \quad (1)$$

4) The results of analyzing the safety of each parking type

In the case of parking time, the null hypothesis is rejected, because statistics value is greater than the critical value of the one-sided test. Accordingly, since the alternative hypothesis, which is that the right angle parking does not take less time than 60° angle parking, is adopted, 60° angle parking can be judged to be superior in efficiency because of shorter parking time than a right angle. In the case of number of reversals, the null hypothesis is rejected, because statistics value is greater than the critical value one-sided test. Accordingly, since the alternative hypothesis is adopted, consisting of right angle parking and does not have a lower number of reversals than the 60° angle parking, 60° angle parking can be judged to be superior in efficiency because of a fewer number of reversals of right angle parking.

Also, if the number of reversals is low, probability of collision between moving vehicles and parking vehicles decreases. Also, it is considered to be good in terms of safety and convenient parking.

Table 13. Results of t-test by parking time and number of reversals

Category	Parking time		Reverse times	
	Right angle parking	60° Parking	Right angle parking	60° Parking
Mean	24.02	14.18	2.28	1.40
Standard Deviation	39.58	31.79	0.58	0.23
# of Sample	600	600	600	600
Variance	35.65		0.43	
Mean difference	0		0	
Degree of freedom	229		229	
t-Value	12.13		10.32	
P(T<=t)	1.19628E-26		5.64075E-21	

3.3 Improvements on parking types

For the efficiency and convenience of railway users' parking, an improved parking plan divides the parking lot into extended parking sections (2.5m~5.1m) based on the 60° angle parking. In consideration of the walking space for pedestrians and their bags and belongings, a pedestrian walkway (1.2m~1.5m) was installed. In addition, the vehicle is operated one-way. The parking method is operating in the 60° rear parking so that it is possible to increase the convenience of railway passengers. In this case, when parked as right angle, the width of the space for pedestrians is 6m. However, when parked as 60° angle, the required Aisle width is only 4.0m. Therefore, the Aisle width with an extra space of 2.0m can afford to switch to right angle parking without increasing the parking space at 60° parking.

Table 14. Comparing the pros and cons of parking types

Category		Right angle parking	60° parking
Safety	Pedestrian space	No walkways	Ensuring sidewalk of 1.2m~1.5m
	Strength	None	Minimizing conflict between pedestrians and vehicles
	Weakness	Conflicts between pedestrians and vehicles	None
	Parking space	More difficult than 60°parking	Relatively easier parking
Efficiency	Parking time	24.02 seconds/car	14.18 seconds/car
	Strength	None	Reduced parking time of 9.84 seconds/car, saved time (41%)
	Weakness	Long parking time	None
	Reverse number	2.28 times/car	1.40 times/car
	Strength	None	Reduced number of reversals of 0.88 times/car, saved time(38.6%)
	Weakness	More reversals during parking	none

4. SAFETY BY PARKING WIDTH

4.1 Setting items to promote safety and efficiency

1) Pedestrian space

The width of the current parking stall was calculated by considering the space to move for parking. Therefore, it is not reflected that the characteristics of passengers are using the railway station and the transit parking. In general, passengers using railway station and transit parking require a wider parking space than the current standard because of carry-on and

luggage for travel and business. There is a need to establish a walking space for parking stalls so as to promote the convenience to rail passengers and the prevention of accidents caused by the friction between pedestrians and vehicles.

2) Minimum visibility range

Before drivers leave the parking block, they must check for vehicles coming from the left side. They need to leave after those vehicles pass by in order to prevent vehicle accidents. Therefore, estimation of minimum safe visibility range is required to prevent vehicle accidents. The required items include the speed of moving vehicles and distance from the driver of parking vehicle to traffic center line. These are separated by the distance between the center line of the passage and parking stall line, and the distance between parking stall lines and driver. Also, it was examined that the average speed of the operating vehicles was 10km/h, the distance between the traffic center line and parking stall line is 3m, and the distance between parking stall lines and driver is 2m.

Table 15. Survey data for calculating the minimum visibility range

Category	Mean travel speed of moving cars	The distance between the centerline of the passage and parking stall Line	The distance between parking stall line and driver
Contents	10km/h	3.0m	2.0m

3) Vehicle width

In order to solve the parking problems, Korea expanded the parking lot and applied to raise installation standards of the parking lot through amending enforcement of parking lots in August 8, 1990. However, the reality is that it failed to present a detailed regulation method that accurately reflects the current trend, such as the enlargement of registered vehicle size since 1990, the rising popularity of big foreign cars over domestic cars, and the increase in large multi-purpose vehicles such as SUVs. The width of standard vehicles was set to 1.7m, because for station and transit parking of large multi-purpose vehicles, a wider parking width calculation is required.

4) Parking time

The shorter the time that rail passengers take to find parking and parking blocks, the larger convenience there is for those passengers. In addition, given the flow system of vehicles in the station and transit parking lots is almost one-way, as the number of waiting vehicles is also reduced due to reduced waiting time.

Table 16. Parking time by parking width

Category	2.3m	2.4m	2.5m	2.6m	2.7m	2.8m	2.9m	3.0m
1	27.3	15.0	12.6	12.8	11.4	10.6	9.4	10.2
2	25.5	16.3	12.6	13.1	12.0	12.3	9.6	11.3
3	23.3	18.7	14.0	13.5	14.5	13.0	9.7	10.2
4	22.3	19.3	14.3	14.0	15.0	13.2	9.9	9.2
5	21.1	19.9	14.4	14.2	15.4	13.7	10.4	9.7
6	23.1	21.2	14.0	13.9	15.3	14.0	10.1	9.0
7	19.5	22.6	16.3	14.8	16.3	15.0	10.4	11.0
8	21.6	23.8	17.3	15.8	15.5	15.5	10.4	10.0
9	23.5	24.0	17.6	15.9	15.5	15.9	10.9	9.3
10	23.8	26.9	20.1	18.9	14.2	17.7	11.0	10.8
Mean	23.1	20.8	15.3	14.7	14.5	14.1	10.2	10.1

Annotation: experimental investigation method (parking time for 0.1m intervals in 2.3m−3.0m)

Reduced vehicle parking time has two benefits: it saves time for those who park at the lot and those who are exiting the lot. We looked into how the parking stall width affects the parking time by increasing the current parking time (2.3m) by 10cm at a time and recording the results.

5) Vehicle trajectory

The shorter the vehicle trajectories, the shorter the front of the vehicle, which means the driver, can stray from the parking area with minimal handle movement. Through this, it can be seen that the width of the vehicle becomes shorter. For measurement of vehicle trajectory, we referenced Kim, Byeong-jung: ("A study on the location of the stop line according to left turn trajectory during the construction of a crossroad on a teardrop-shaped traffic island." 2006.). For cars, the front wheel can be operated through the steering wheel, which means that the rotating radius for the front wheel axle shafts and rear wheel axle shafts are different. For the front wheels, the steering wheel is frequently turned for the inner side of the wheels, ensuring smooth rotation. The turning radius of the outer side is calculated with the steering angle, center distance, etc... As variables for calculating the trajectory of vehicles, the outer steering angle (☐), inner steering angle ☐ and wheel track (☐ were calculated through examining the vehicles that are currently in the market. Other variables are applied based on the specifications in vehicle design criteria.

Table 17. The mean value of the steering angle and wheel track of domestic vehicles

Category	Wheel track		Steering angle	
	Front wheel	Rear wheel	Outer	Inner
Small cars	1.44m	1.44m	38°	31°
Medium & Large cars	1.92m	1.75m	45°	34°
Semi-trailer	2.05m	1.86m	28°	20°

Table 18. Specifications in vehicle design criteria

Category	Length	Width	Height	Wheel Base	Projecting front length	Back projected length	Minimum turning radius
Small cars	4.7m	1.7m	2.0m	2.7m	0.8m	1.2m	6.0m
Medium & Large cars	13.0m	2.5m	4.0m	6.5m	1.5m	4.0m	12.0m
Semi-trailer	16.7m	2.5m	4.0m	Front:4.2m Rear:9.0m	1.3m	2.2m	12.0m

4.2 Proper width of parking

The two hypotheses were set up in order to estimate the proper width for parking stalls in station and transfer parking lots. The minimum (Min) and maximum (Max) of the parking width were calculated. Proper width of parking in between the two values is calculated through regression analysis.

Table 19. Hypotheses for calculating the proper width of parking

Assumption 1: As the width of parking is widened, the convenience of rail passengers will be increased, and safety will then become increased because minimum safety vision is ensured.
Assumption 2: As for vehicles parked on the right side in a one-way, the driver should always leave the parking block after checking the vehicles on to the left side of the road.

1) Minimum (Min) Parking Width

The legal installation standard for parking width is defined as more than 2.3m for general

types and more than 2.5m for extended types. Thus, except for the standard vehicle width of 1.7m, the left and right margin is 0.3m. This is smaller than the shoulder width of the Korean standard body. It is also considered to be inconvenient when the railway passengers carry baggage. Additionally, small cars are on the decline. Medium and large vehicles are on the rise, so this should be considered to reflect the vehicle width standard of 1.7m. However, for the purpose of this study, the current vehicle width of 1.7m will be applied to estimate the minimum parking width. As the result of estimating the minimum width of parking, it was estimated to be 2.5m in consideration of a vehicle width of 1.7m and pedestrian space of 0.4m. This is the same as the extended type in the parking lot law enforcement.

Table 20. Installation criteria and operational status of parking width

Category	Parking width(m)	Remarks
Enforcement Rules of Parking Lots	Small Type : More than 2.0m Standard Type : More than 2.3m Extended Type : More than 2.5m Disabled Type : More than 3.3m	Outside Parallel Parking

Table 21. Minimum (min) parking width

Category	Parking width(m)
Current installation and operation status	▪ Parking width : 2.3m ▪ Pedestrian space(0.3m)+Vehicle width(1.7m)+Pedestrian space(0.3m)
Minimum(Min) parking width	▪ Minimum(Min) parking width : 2.5m ▪ Pedestrian space(0.4m)+Vehicle width(1.7m)+Pedestrian space(0.4m) ▪ Considering the shoulder width of Korean standards

2) A maximum parking width

In order to estimate a maximum (Max) parking width; Step 1: Estimate mileage of moving vehicles; Step 2: Estimate a minimum visibility range for identifying moving vehicles; Step 3: Estimate a maximum (Max) parking width.

(1) Step 1: the mileage calculation of moving vehicles (d_1)

The mileage of moving vehicles was deduced from the stopping sight distances formula. Stopping sight distance consists of the mileage and braking distances during the reaction time. Mileage is the driving distance during the reaction time when drivers notice obstacles and apply their brakes. This is determined by 1.5 seconds for judging the risk factor, and 1.0 seconds for applying the brake (a total of 2.5 seconds). According to Assumption 2, the driver leaves the parking block after they check for moving vehicles on the left. Accordingly, the driver does not have to apply their brake. Therefore, in our calculation, we removed the 1.0 second it took to operate the brake pedal of the moving vehicle and only considered the 1.5 seconds it took to determine the risk factor. Estimated mileage of moving vehicles was calculated as 4.2m.

Table 22. Step 1: Mileage calculation of moving vehicles (d_1)

Category	Contents
Calculation Formula	$d_1 = vt = \frac{V}{3.6}t$ ▪ d_1: Mileage during the reaction time(m), ▪ v, V : Design speed(m/sec, km/hr) , ▪ t : Reaction time
Calculation Results	$d_1 = vt = \frac{10}{3.6} \times 1.5 = 4.2m$

	▪ V :10km/hr (Average travel time through field investigation), ▪ t : 1.5 Seconds

(2) Step 2: the minimum visibility range to identify moving vehicles (d_2)

After measuring the distance between the driver of parking vehicle to traffic center line and the distance between the drivers to the parking stall line, we calculated the minimum visibility width for checking moving vehicles by applying a proportional expression. A minimum visibility width was estimated to be at least 1.7m. A vehicle parked with a visibility width of at least 1.7m or more is considered a value for which the parked vehicle can check the moving vehicle and the moving vehicle can drive without having to apply its brake.

Table 23. Step2: Minimum visibility range (d_2)

Category	Contents
Calculation formula	$d_2 = d_1 \times \frac{s_2}{s_1}$ ▪ d_2 : Visibility width of the parking vehicle driver(m) ▪ s_1 : Distance between the driver of parked vehicle and traffic centerline(m) ▪ s_2 : Distance from the driver of parked vehicle to parking stall line(m)
Calculation results	$d_2 = 4.2 \times \frac{2.0}{5.0} = 1.7m$ ▪ s_1 : 5.0m (Passage width 6.0×0.5+ s_2) ▪ s_2 : 2.0m (Mean distance through field investigation)

(3) Step 3: the maximum (Max) parking width (d_3)

The maximum (Max) parking width was drawn to 3.0m, considering the minimum visibility width of 1.7m estimated from Step 2 and the shoulder width of Koreans.

Table 24. Step3: The Maximum (Max) parking width (d_3)

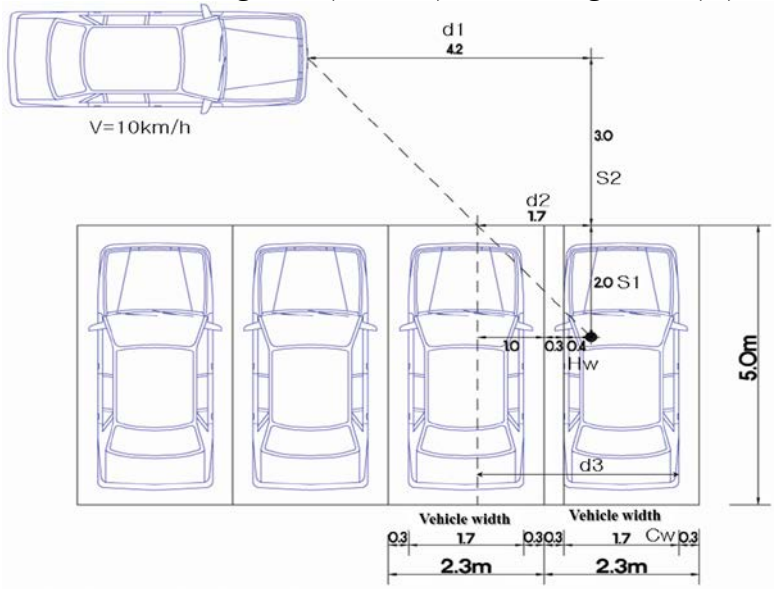
Category	Contents
Calculation formula	$d_3 = d_2 + Cw - Hw$, $d_3 = \frac{V}{3.6} t \times \frac{s_1}{s_2} + Cw - Hw$ ▪ d_2 : Visibility width of the parking vehicle driver(m) ▪ Cw : Vehicle width(m) ▪ Hw : Korean shoulder width(m)
Calculation results	$d_3 = 1.7 + 1.7 - 0.4 = 3.0m = (0.3 + 1.7 + 0.3) + (1.7 - 0.4 - 0.3) - 0.3 = 3.0m$

3) The proper parking width

For determining the proper parking width of station and transit parking, a minimum parking width of 2.5m and a maximum parking width of 3.0m were calculated. The proper parking width will be determined between these two values. However, the current parking width installed in the station and transit parking lot is usually 2.3m, and there aren't any parking lots with parking blocks of 2.5m - 3.0m width. So by selecting the test vehicle and subjects, we increased the width of each by 10cm based on 2.5m. After examining the parking time data, we performed regression analysis. The parking width was estimated from the deducted model equation through a simple linear regression analysis with the parking time as the dependent variable and the parking width as the independent variable. Model equation is equation (2).

$$Y = 270.42X^{-3.0033}, (R^2 = 0.76) \quad (2)$$

Here, Y: Parking time (seconds), X: Parking width (m)



Figures 3 Maximum (Max) parking width

As the result of equation (2), if the minimum (Min) parking width is 2.5m, the parking time is 17.25 seconds. If the maximum (Max) parking width is 3.0m, the parking time is 9.98 seconds. Therefore, as the result of analyzing the parking time of the experiment data between Min (2.5m, 17.25 seconds/car) and Max (3.0m, 9.98 seconds/car), the mode was analyzed by 14 seconds/car. The proper parking width of mode (14 seconds/car) was estimated to about 2.7m. If a proper parking width is installed to 2.7m, the parking time is shorter (8.47 seconds/car) than the parking time of parking width installed to 2.3m in the current station and transit parking. This reduces parking time of about 38%. In addition, if the proper parking width is 2.7m, the convenience for passengers using the station and transit parking will be higher, as the width of walking space at the side of the vehicle expands to 0.5m.

Table 25. Proper parking width

Category	Parking width(m)	Parking time (seconds/vehicle)
Installed operation width	2.3	22.16
Minimum(Min) parking width	2.5	17.25
Maximum(Max) parking width	3.0	9.98
Proper parking width	2.7	13.69

4) Analysis of the reduction effect of road width by change in parking width

Through the calculation method of the driving trajectory, the outer radius (Rm) is drawn to 5.799m and the inner radius (Ri) is drawn to 2.924m. By utilizing CAD based on the derived outer radius and the inner radius, we can construct the vehicle trajectory.

Table 26. Vehicle trajectory calculation

Category	Value	Category	Value
Inner radius(Ri)	2.924	Outer radius(Rm)	5.799
Outer front wheel turning radius(R0)	5.242	Outer front wheel turning radius(Rw)	3.054
Center-to-center distance(α)	2.700	Vehicle width(W)	1.700
Front projected distance(Uf)	0.800	Prospective rear center-to-center distance(p)	1.440
Deflection angle of the outer front wheel(β)	31	Distance between car body and inner wheel (Wi)	0.130

-	-	(Ww)	2.189

When the parking width is 2.3m, the car can rotate in the Aisle width of 4.50m. When the parking width is 2.7m, the car can rotate in the parking surface width of 4.16m. Therefore, if the parking width widens from 2.3m to 2.7m, the parking surface width is reduced to 4.50m from 4.16m for the parked vehicle to leave the parking block. It has about 7.6% reduction in the car way width.

Table 27. Analysis of the aisle width reduction effect

Category	Parking width		Reduction effect
	2.30m	2.70m	
Aisle width	4.50m	4.16m	-7.6%

4.3 Improvements in parking width

This study proposes improvements in consideration of the vehicle and pedestrian area based on the proper parking width of 2.7m, and that takes all into account (vehicle, pedestrian area, and bags).

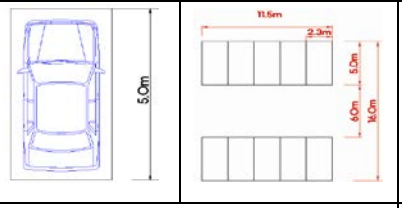
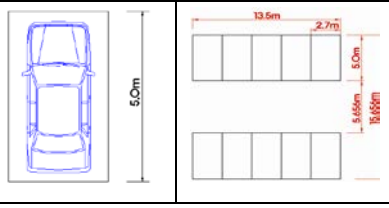
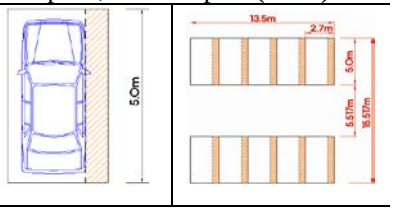
1) Adequate parking width in case of considering vehicle, pedestrian space

In the case of installing 0.5m for the left and right sides as walk space from the proper parking width of 2.7m has increased to 0.2m and is possible to secure a minimum visibility width of 1.7m, compared with the margin of 0.3m of the currently installed parking width. Also, the driving trajectory is reduced to 4.16m from 4.50m due to the effect of a 7.6% reduction.

2) Adequate parking width in consideration of vehicle, pedestrian space, and bags

In the case of installing a left walk space of 0.4m and a right carrier space from the proper parking width of 2.7m, a left walk space is increased to 0.1m and is possible to utilize a right carrier space of 0.6m, compared with a margin of 0.3m of the currently installed parking width. Also, a minimum visibility width of 1.7m can be secured and driving trajectory is reduced to 4.02m from 4.50m as the effect of a 10.7% reduction.

Table 28. Comparing parking area according to improvement in parking width

Current parking width(2.3m)	Considering vehicle, pedestrian space(2.7m)	Considering vehicle, pedestrian space, carrier space(2.7m)
		
Parking cars : 10 cars Parking area: 184m^2	Parking cars : 10 cars Parking area: 211m^2	Parking cars : 10 cars Parking area: 209m^2

3) Comparing strengths and weaknesses for improvement of parking width

As the movement of pedestrian space and the bag space can be ensured in terms of the passengers using the station and transit parking, the safety of the pedestrian space will be guaranteed, and will result in efficiency for the reduction of parking time and saving the waiting time of moving vehicles. In addition, a disadvantage is that the cost increases for the owner of the parking space because the parking area increases as the parking width increases. However, it is effective for decreasing parking width by changing the vehicle trajectory and can provide high safety and efficiency for passengers using the station and transit parking.

Based on the appropriate parking width of 2.7m as calculated in this study, the advantages and disadvantages of Improvement 1 (consideration of vehicle and pedestrian space) and improvement 2 (consideration of vehicle, pedestrian space, and bags compared to the <Table 29> as follows.

Table 29. Comparing strengths and weaknesses for improvement in parking width

Category		Before improvement(2.3m)	Considering vehicle, pedestrian space(2.7m)	Considering vehicle, pedestrian space, bags (2.7m)
Safety	Pedestrian space	Left : 0.3m, Right : 0.3m	Left : 0.5m, Right : 0.5m	Left : 0.4m, Right : 0.6m
	Strength	Minimum in parking area ($184m^2$/10 cars)	0.2m Increase in pedestrian space	Pedestrian space 0.1m increase with carrier space
	Weakness	Confined pedestrian space of rail passengers	14.5% Increase in parking area($211m^2$/10cars)	13.6% Increase in parking area($209m^2$/10cars)
	Minimum visibility range	1.7m	1.7m	1.7m
Efficiency	Parking time	22.16 seconds/car	13.69 seconds/car	13.69 seconds/car
	Strength	-	Reduction in parking time(8.47seconds/car) Saving time (38%)	Reduction in parking time(8.47seconds/car) Saving time (38%)
	Weakness	Long parking time delays for vehicles	-	-
	Aisle width according to travel trajectory	4.50m	4.16m	4.02m
	Strength	-	7.6% Reduction in aisle width	10.7% Reduction in aisle width
	Weakness	Increasing the area secured in parking lot	-	-

5. SAFETY ACCORDING TO VEHICLE FLOW

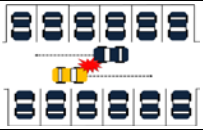
Not only is vehicle flow a major factor causing conflict but also it should be a priority when considering pedestrian safety. In addition, while designing and managing the parking lot, potential hazards due to vehicle flow should be identified and improvement plans should be established. In this study, using traffic conflict techniques, we predicted the risk of accidents that occur due to vehicle flow in order to identify potential risks of such vehicle flow.

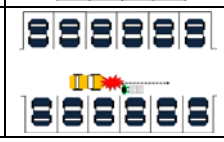
5.1 Establishment of standard for analysis of parking lot collisions

1) Conflicting types of parking lots

As accidents can be classified according to the type of collision, traffic conflicts may also be classified according to the vehicle operation type of the driver. The form of general parking lot conflicts can be divided as shown <Table 30>.

Table 30. Types of conflicts in parking lots

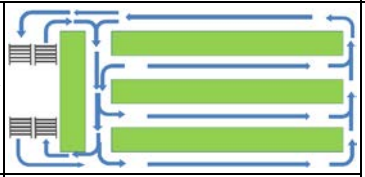
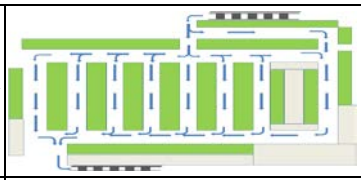
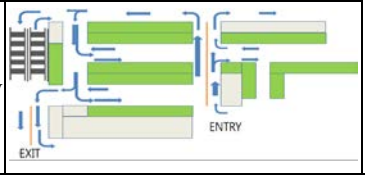
Types of conflicts	Types	Description
Conflict on rear side		▪ Conflict between vehicles moving in the same direction
Cross conflict		▪ Conflict between vehicles moving in the same direction

Conflict(1) in the same direction		▪ Conflict between a vehicle moving right and a vehicle moving left in the same direction
Conflict(2) in the same direction		▪ Conflict between a vehicle going straight and a vehicle moving right(left) in the same direction
Conflict(3) in the same direction		▪ Conflict between a vehicle coming out of parking block and a vehicle moving straight
Conflict with a pedestrian		▪ Conflict between a pedestrian and a vehicle entering parking lot

2) Vehicle flow and types of parking lots

Station and transit parking can be divided into integrated entry/exit and separated entry/exit. They can also be subdivided into two-way and one-way traffic. Furthermore, considering the movement characteristics of the vehicle according to the type of parking lot, we analyzed each type of vehicle flow.

Table 31. Vehicle flow by types of parking lots

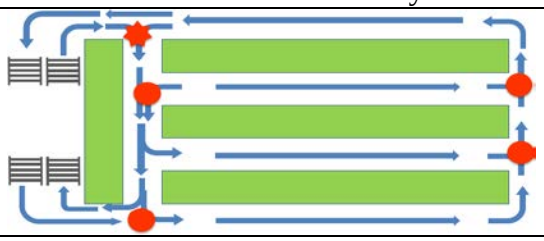
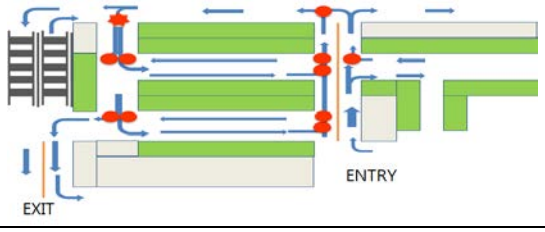
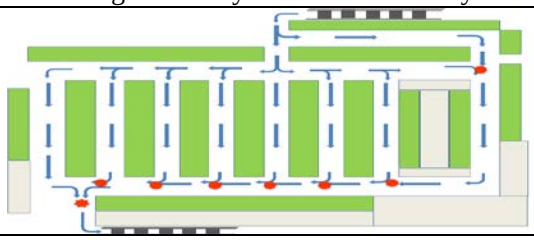
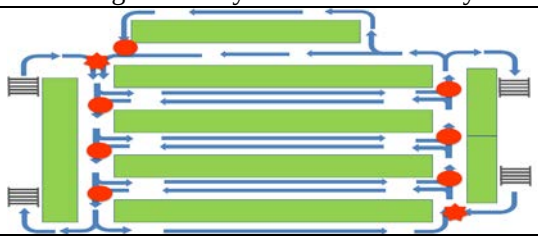
Parking types	Vehicle flow		Parking types	Vehicle flow	
Integrated entry and exit	One-way		Separated entry and exit	One-way	
	Two-way			Two-way	

5.2 Conflicts in parking lots

Most accidents in parking lots are minor injuries or accidents involving material damage. Therefore, reported accidents are extremely rare, and are very difficult to discern the degree of accident risk with the type of parking lot. We determined the degree of accident risk through analyzing vehicle flow and type of conflict by type of parking lot. In the case of one-way traffic parking lots with integrated entry and exit, there is an advantage in that it does not cause cross conflicts and is less likely to cause occurrence of conflict than most other parking lots. However, there is a disadvantage in that unnecessary passages occur, since the vehicles moving between floors must make a detour. In the case of two-way traffic parking lots with integrated entry and exit, there is a disadvantage that conflicts in the same direction are more than two times higher than in one-way traffic parking lots as well as a higher occurrence of cross conflicts in all parking areas. On the other hand, it has the advantage of reducing unnecessary passage of vehicles. In the case of one-way traffic parking lots with separated entry and exit, this is also likely the occurrence of cross conflicts similar to one-way traffic parking lots with integrated entry and exit. However, there is a higher likelihood of conflict between pedestrians and vehicles, because it has disadvantages that vehicle detour distance increases as there are more cars and the parking lot is larger. In the case of two-way traffic parking lots with separated entry and exit, there is a disadvantage that conflicts in the same direction are more than two times higher than in one-way traffic parking lots as well as a

higher occurrence of cross conflicts in all parking areas. But this has an advantage of reducing unnecessary passage of vehicles.

Table 32. Analysis on conflicts by types of parking lots

	
Integrated entry and exit in one-way	Integrated entry and exit in two-way
	
Separated entry and exit in one-way	Separated entry and exit in two-way

The result of comparing and analyzing the advantages and disadvantages for conflict characteristics of each type of parking lot, integrated entry and exit had a longer vehicle movement distance than the separated entry and exit. Also, the difference between one-way and two-way traffic was analyzed according to the cross-conflict occurrence and number of conflicts in the same direction.

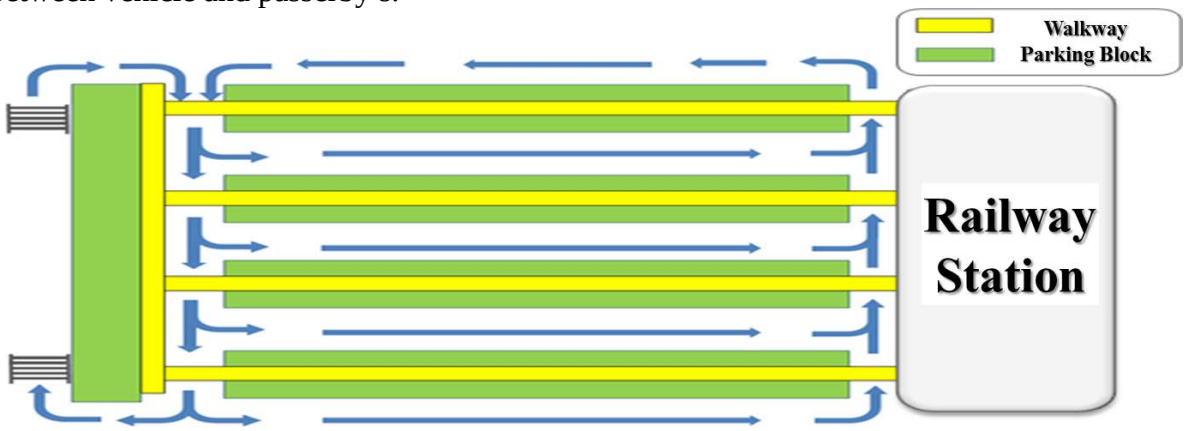
Table 33. Conflict characteristics of each type of parking lot

Type of parking lot		Strength	Weakness
Integrated entry and exit	Weakness	▪ The fewest conflicts in four types ▪ No cross conflicts	▪ Long Vehicle Flow
	Two-way	▪ The shortest vehicle flow among four types ▪ Easy selection of parking location in parking lot	▪ Conflicts between vehicles between pedestrians and cross conflicts in all sectors ▪ Number of conflicts between pedestrians is more than twice that of one-way
Separated entry and exit	One-way	▪ Less conflicts between vehicles ▪ No cross collisions	▪ Longest vehicle flow
	Two-way	▪ Short vehicle flow ▪ Easy selection of parking location in parking lot	▪ Conflicts between vehicles between pedestrians and cross conflicts in all sectors ▪ Number of conflicts between pedestrians is more than twice that of one-way

5.3 Improvement in vehicle flow

The result of analyzing conflict characteristics of each type of parking lot, one-way traffic parking lots with integrated entry and exit represent the fewest for the number of conflicts between pedestrians and vehicles and conflicts between vehicles. Also, one-way traffic is the fewest for conflicts between pedestrians and vehicles. Therefore, when designing a parking lot, it is preferable to design for one-way traffic rather than two-way traffic. For the safety of pedestrians, separation of pedestrian vehicle flow is needed. When installing a pedestrian walkway in station and transit parking, it should be installed in a width of 1.3m or more, and differentiated from the vehicle movement space with a different color. It is excellent for convenience and safety to have pedestrian walkway installed between the parking blocks, in

order to guarantee easy pedestrian access to the luggage compartments and to avoid conflicts between vehicle and passerby's.



Figures 4. Improvement in transferring and parking lot of railway station

6. EFFICIENCY DISCUSSION OF PARKING LOT INSTALLATION

6.1 Efficiency discussion of indoor parking lot from the operator's perspective

In the case of indoor parking lots, spatial limitations exist due to the establishment of pillars, etc, it should be applied to a 90°angle parking. Also, the width of parking blocks should be applied to 2.7m. Additionally, the vehicle flow is operated with one-way traffic. The Traffic Passage width is applied as 6.0m according to 90°angle reverse parking. The pedestrian walkway is applied to 1.3m. Under the same conditions as above, we reviewed the existing parking lot and the installation efficiency of parking area. The latest trend of parking surface installment for currently existing parking lots is to install the extended type (2.5m) rather than standard type (2.3m). So we compared extended type. According to the results compared to the Standard and Extended parking lots, based on the width of 80m, 90°angle parking with the width of 2.5m could park 32 cars and 90°angle parking with the width of 2.7m could park 29cars. This is a decrease of approximately 9.4% in parking blocks. As installing a pedestrian walkway between the parking blocks, an additional length equal to the width of the pedestrian walkway is required.

6.2 Efficiency discussion of outdoor parking lots from the lot owner's perspective

Outdoor parking lots do not have spatial limitations according to established facilities. Therefore, we installed the 60°angle parking, and reviewed the installation efficiency of parking blocks in comparison to 90°angle parking. The width of the parking stalls is applied to 2.7m. The vehicle flow is operated as one-way traffic. Traffic Passage width is 4.5m in accordance with 60°angle parking, and the pedestrian walkway is applied to 1.5m. Under the same conditions as above, we reviewed the installation efficiency of parking area compared with the extended (2.5m) parking lot. According to the results upon reviewing the installation efficiency of parking area for the horizontal width of 80m, 90°angle parking (width 2.5m) could fit 32 cars and 90°angle parking (width 2.7m) could fit 25 cars. This is an approximately 21.9% decrease in the number of parking blocks. 90°angle parking and angle parking have a difference due to length. Angle parking needs 0.7m more than 90°angle parking. Also, it requires less in width of 2.0m. Thus, if a margin of 1.3m occurs, a pedestrian walkway is secured, and the vertical length does not require additional space.

7. CONCLUSION

By targeting station and transit parking lots, we analyzed the safety of parking lots depending on the parking type, the parking width and vehicle flow. To see whether there is a difference in parking time and number of reversals, we analyzed the 90°angle parking and 60°angle parking types that are operated in most of the current parking lots where the t-test was applied. As a result, 60°angle parking had a 9.5seconds/car decrease in parking time compared to 90°angle parking. This amounted to a reduction effect of 40% or more. Also, for the number of reversals during parking, the 90°angle parking reversed 2.29times/car and the 60°angle parking reversed 1.41times/car, a time savings of 38.4%. However, 60°angle parking is not appropriate in indoor parking lots with pillars, and it can be applicable to outdoor parking lots. In terms of parking width, based on a minimum width of 2.3m that is currently being operated, an experiment was carried out in accordance with the actual parking width with a gap of 0.1m and up to 3m. Measuring the actual parking time, and through regression analysis, we calculated the proper parking width. As a result, the appropriate parking width was 2.7m when considering the safety of the vehicle and the walking area. In terms of vehicle flow, if operating a one-way traffic parking lot with separated entry and exit, the safety is higher according to the results of conflict analysis. It is also appropriate to install a separate pedestrian walkway in order to avoid conflicts of vehicles and pedestrians. This is determined based on the efficiency and safety of the railway user. In addition, because it is necessary to compare the efficiency of the installation from the lot owner's perspective, we also reviewed the installation efficiency of the parking block. According to the examination result, the parking blocks of 90.6% were decreased in accordance with increasing the parking width of 0.2m in indoor parking lots. Additionally, the parking blocks of 78.1% were decreased in accordance with increasing the parking width of 0.2m and changing to 60°angle parking in outdoor parking lots. Both cases, however, had the advantage of usability for the movement of pedestrians and bags in order to secure pedestrian walkways. Lastly, this study had limitations for data collection, according to data that was derived by the experimental method regarding the data of parking time based on parking width. In the future, data analysis from multilateral aspects is required, considering human factors such as parking time by gender, age, driving experience and vehicle size.

ACKNOWLEDGEMENTS

This research was supported by a grant (14RTRP-B067918-02) from the Railroad Technology Research Program funded by Ministry of Land, Infrastructure and Transport of the Korean Government.

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