INCREASING AIRPORT OPERATION SAFETY BASED ON UPDATED OR ENHANCED AIRPORT PAVEMENT MARKINGS: A CASE STUDY

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By

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ABSTRACT

This paper presents the pavement markings implementations at Kaousiung International Airport (KHH), Taiwan as case study in relation to airport operation safety. The two-year marking projects that focused on updating or improving the identified markings issues consisted of relocating touchdown zone markings, redeveloping taxiway markings, and redesigning and improving apron markings. Each update or improvement project was evaluated to ensure compatibility with International Civil Aviation Organization (ICAO) standards prior to construction. The objective of this paper is to present the markings issues identified at KHH, discuss how those issues came about, and explain how the airport authorities dealt with those issues. Through the comprehensive review and construction efforts in pavement markings, the updated or improved configurations of pavement markings at KHH meet the ICAO standards, addressed previously identified issues, as well as increased the aircraft operation safety and ground movement safety.

INTRODUCTION

Airport pavement markings are important components of visual aid systems at airports. Adequate visibility and a clearly defined horizon can lead to safe and sound aircraft maneuverings. Relevant airport pavement markings standards have been documented by the three major aviation organizations in the world: the Federal Aviation Administration (FAA), the International Civil Aviation Organization (ICAO), and the International Air Transport Association (IATA). Pavement markings configurations can vary depending on the geometric conditions of runways, taxiways, and aprons. Lead-in line markings, for example, contain three types of marking patterns in aprons, e.g. simple nose-wheel lead-in line, offset nose-wheel lead-in line, and straight lead-in line that could result in different performance. Selecting appropriate marking configurations suitable to the airport's operation environment might sometimes present a challenge to airport personnel. Not only they must follow aviation standards, but they must also rely on airport engineers' experience and knowledge to understand these standards as they relate to the airport operation environment.

As of 2000, the ICAO standards have been adopted by the Civil Aeronautics Administration (CAA), Taiwan, as guidance for operational procedures and airport facilities among all commercial airports. In response to the CAA's amendment, the Kaohsiung International Airport (KHH) authorities embarked on a master plan to evaluate the compatibility of airport operational documents, procedures, and facilities with ICAO standards. A number of projects were generated to update or modify previous procedures or standards of airport facilities using the mandated subjects required by the ICAO standards. A two-year plan for airport pavement markings projects was created to update or modify the pavement markings to ensure compliance with the ICAO standards. In addition, some existing marking configurations were found to not work effectively in directing airplane movements. Improvements of marking configurations on such identified areas were also included on the project. Each update or improvement was evaluated to ensure compatibility with ICAO standards prior to construction. Those projects consisted of the following areas (Figure 1):

1. Runway 09/27: Relocate touchdown zone markings at both Runway 09 and 27 ends. A sensitivity analysis associated with aircraft descend boundary lines was conducted to calculate the vertical clearance distances between the descending aircraft's wheels and the runway threshold.
2. Taxiway S and cargo apron: Redevelop taxiway markings along Taxiway S and improve part of pavement markings at the intersection of Taxiway S, Taxiway G, and cargo apron.
3. International apron, far-end apron, and domestic apron: Design safety-zone markings in international apron, far-end apron, and domestic apron areas. Adjust and improve part of pavement markings in the areas of far-end apron and domestic apron. A series of sensitivity analyses associated with aircraft movement boundary lines were conducted to calculate the wing tip clearances between the parked/maneuvering aircraft and the nearest object.

The ICAO standards were used in all projects. In addition, the IATA and FAA standards were also used in parts of the pavement markings projects when the topics were not available or specifically addressed in the ICAO standards. The objective of this paper is to present the markings issues identified at KHH, discuss how those issues came about, and explain how the airport authorities dealt with those issues.

FIGURE 1 Layout of Kaohsiung International Airport

PAVEMENT MARKINGS PROJECT ON RUNWAY 09/27

Statement of Problem

Runway 09/27 at Kaohsiung International Airport was built in 1987. Runway markings have provided visual aids during aircraft landings for over 2 decades. In addition to aiming point markings, the Precise Approach Path Indicator (PAPI) is the primary visual cue on the runway provided for aircraft descend. The pilots initiate descent by aiming the aircraft at the visualized aiming points known as aiming point markings (dimension of 10 m by 60 m at KHH) associated with the PAPI's signals and make final approach judgments along the flight slope path to ensure a safe landing within the touchdown zone. Based on the markings review, the beginning of the aiming point markings was not coincident with the origin of PAPI system (Figure 2a) as required by the ICAO Annex 14, Section 5.2.5.4.

The location of the PAPI is a function of the presence of Instrument Landing System (ILS) glide path or Microwave Landing System (MLS) minimum glide path. Moreover, the location of PAPI should be such that in no case will the wheel clearances over the runway threshold be lower than what is specified in the ICAO standards. A sensitivity analysis was made to evaluate the compatibility of the locations of the PAPI system and aiming point markings, and to study the relationship between the wheel clearances of descending airplanes and the locations of aiming point markings and PAPI system.

Sensitivity Analysis and Problem Solutions

According to the field investigation findings, the position of aiming point markings was located 110 m ahead of the PAPI system at the 09 runway direction. The PAPI system was located 21 m ahead of the aiming point markings at the 27 runway direction. Thus, the 09 runway direction was selected to study the relationship between the potential risks and relocation of aiming point markings.

FIGURE 2a Geometric relationship between aiming point markings and the PAPI on the 09 runway direction at KHH

Figure 2b depicts the schematic of the geometric relationship between the PAPI, aiming point marking, runway threshold, and the decent aircraft. The slope angle of an aircraft to the aiming points (α) and the PAPI system (β) expresses the following relation:

$$\frac{\tan\alpha}{\tan\beta} = \frac{110}{D-110} \tag{1}$$

Where α — The slope angle (alpha) from the landing aircraft to the front edge of aiming point markings

β — The slope angle (beta) from the landing aircraft to the front edge of PAPI system

D — the horizontal distance between the landing aircraft to the front edge of PAPI system

The vertical clearance distance between the front edge of the runway threshold and the descent aircraft's wheels known as the wheel clearance over the threshold has the following relations (Figure 2b).

$$S_\alpha = H_1 - S$$
$$S_\beta = H_2 - S \tag{2}$$

Where S_α — The wheel clearance over the runway threshold at the slope angle of alpha

S_β — The wheel clearance over the runway threshold at the slope angle of beta

S — The eye-to-wheel height of aircraft in the approach configuration.

H_1 — The eye-to-ground height of aircraft in the slope angle of alpha

H_2 — The eye-to-ground height of aircraft in the slope angle of beta

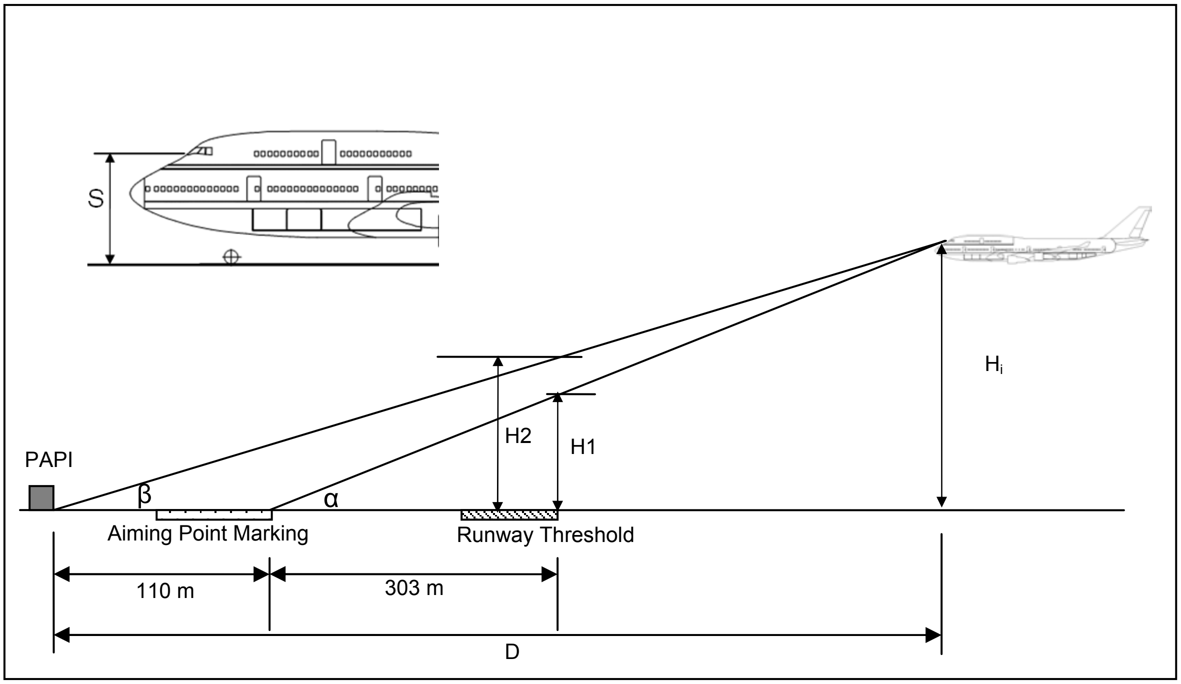

FIGURE 2b Visual approach geometry

An analysis was carried out to estimate the changes of the wheel clearance between the slope angles of alpha and beta. The normal slope angle of 3 degree for the descending aircraft was used in the flight path. However, slope angles ranging from 2.7 to 3.3 degree were utilized in the analysis using Eq. 1 and 2 to calculate the changes of wheel clearance as the slope angle varied. The most demanding aircraft was determined to be a B747-400. In addition, the over-height obstacles located within the approach surface were included to study the effect of slope angle changes on the required vertical clearance distance.

As shown in Figure 3, the analysis indicates that out of four aircraft approach boundary envelopes, the critical slope was about 1.0 %. At this slope the angles of alpha and beta did not exceed the normal slope angle of 3 degrees and still maintained sufficient vertical distances above the elevations of obstacles within the approach surface.

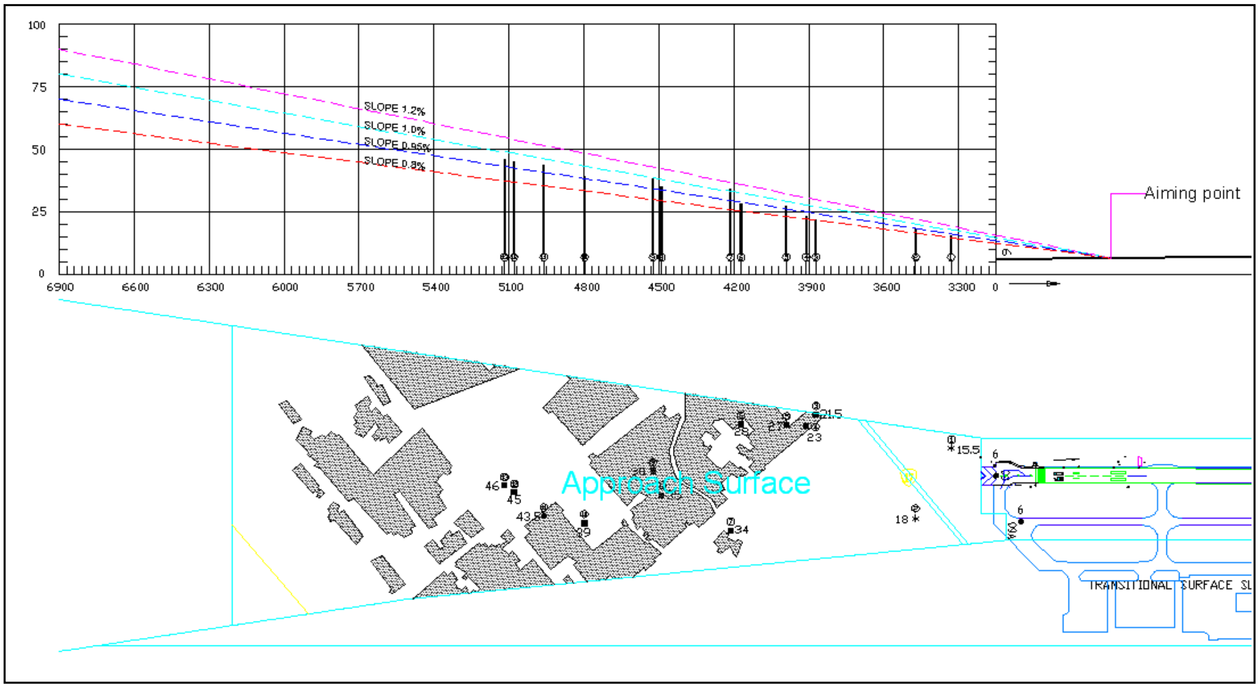

FIGURE 3 Visual Approach Geometry Evaluation
Note: numbers represent locations of features that present vertical clearance issues

Focusing on the runway threshold area, some potential issues were noticed. Table 1 specifies the wheel clearances for 4 aircraft categories required by the ICAO. The desired wheel clearance and minimum wheel clearance for a B747-400 airplane are 9 m and 6 m, respectively.

TABLE 1 ICAO wheel clearance over runway threshold

eye-to-wheel height of airplane in the approach configuration	Desired wheel clearance, (m)	Minimum wheel clearance, (m)
up to but not including 3 m	6	3
3 m up to but not including 5 m	9	4
5 m up to but not including 8 m	9	5
8 m up to but not including 14 m	9	6

The results of the analysis on the wheel clearance between the approaching configurations of alpha and beta angle are shown in Table 2. Clearly, the wheel clearances along the alpha slope (S_α) under various angles are below the required minimum wheel clearance of 6 m. The results revealed that if the pilots aim at the existing aiming point markings to descend the aircraft for landing, the aircraft's wheel clearances over the runway threshold would be lower than the specified ICAO standards. Thus the origin of aiming point markings needed to be relocated. In terms of the approaching configuration of beta slope, the calculated wheel clearances (S_β) resulting from slope angles of 2.7 degree to 3.3 degree are greater than the minimum wheel clearance requirement. Thus, the existing location of PAPI appears to be appropriate for visual cues during aircraft landings. After assessing the results from the sensitivity analysis, the KHH authorities decided to relocate the aiming point markings at both runway 09 and 27 ends to keep aiming point markings aligned with the PAPI system. The relocation project of touchdown zone markings took 7 consecutive days to remove and repaint aiming point markings and corresponding touchdown zone markings at runway 09 and 27 ends.

TABLE 2 Wheel clearance over runway threshold between two approaching configurations

slope angle, degree	Wheel clearance over runway threshold (m)	
	Approaching configuration in the angle of alpha (S_α)	Approaching configuration in the angle of beta (S_β)
2.7	1.3	6.5
2.8	1.8	7.2
2.9	2.3	7.9
3	2.9	8.6
3.1	3.4	9.4
3.2	3.9	10.1
3.3	4.5	10.8

PAVEMENT MARKING PROJECT ON TAXIWAY S

Statement of Problem

Before January of 2003, Taxiway S was named Runway 09R/27L and the current Runway 09/27 was called Runway 09L/27R (Figure 4a). However, Runway 09R/27L had been decommissioned and is currently used for aircraft taxiing activities. Pavement markings placed on Runway 09R/27L were otherwise shown for runway operations. Sometimes, pilots were confused by such marking configurations while descending the aircraft to the landing runway. This issue needed to be improved without any further analysis.

FIGURE 4a Before marking improvements on Taxiway S (previously RWY 09R/27L)

Problem Solutions

In an effort to provide clear and well-defined areas for safe aircraft maneuvering, the following recommendations were proposed:

1. Runway 09R/27L was renamed as Taxiway S so as to provide clear airport configurations (Runway 09/27, Taxiway A, B, C,…S, etc.)
2. Improper pavement markings on Taxiway S were replaced with updated pavement markings for use of taxiway activities.

3. The width of Taxiway S was reduced from 60 m to 23 m since having a width of 60 m might confuse pilots when approaching the aircraft to the landing runway. A reduced width of 23 m associated with the transverse stripe markings and corresponding edge lighting systems were designed, which would make Taxiway S a normal taxiway for aircraft taxiing operations.
4. Existing holding bays, runway-holding positions, intermediate holding positions and road-holding positions (pattern B) were replaced with updated markings (pattern A) in order to suit the geometric conditions along perpendicular taxiways and cargo apron. The clearance distance between taxiway centerline to the nearest object was determined to be 47.5 m as required by the ICAO and IATA standards (48.5m by the FAA). For details of pattern B and A, please refer to the ICAO standards *(2).*

A completion figure of markings improvements along Taxiway S is shown below in Figure 4b and also can be seen in Figure 1.

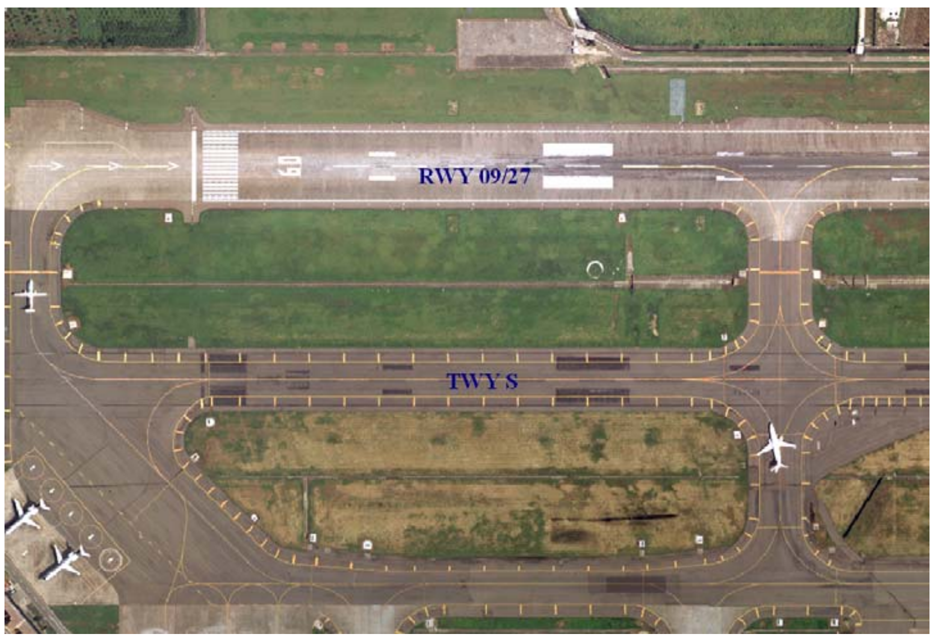

FIGURE 4b Completion of TWY S marking redevelopment
Note: RWY 09R/27L was renamed to Taxiway S as of January, 2003

PAVEMENT MARKING PROJECT ON INTERSECTION OF TAXIWAY S, G, AND CARGO APRON

Statement of Problem

An issue was found at the intersection of Taxiway S, Taxiway G, and cargo apron (Figure 1). The Division of Operation received complaints from pilots that the markings on the intersection of Taxiway S and G were too complex when operating aircraft to this area during low visibility weather conditions. Two ground incidents where passenger airplanes mistakenly made a wrong turn to the cargo apron at this section were reported (Figure 4c). Although, the marking configurations at this area were originally designed in accordance with the ICAO standards, the performance of pavement markings at this area did not work effectively in directing taxiing airplanes to turn to Taxiway G. Based on the marking review, the simple nose-wheel lead-in lines were placed in cargo apron and the intersection of Taxiway S and G (Figure 4c). The reflective grass beans were also added to all of pavement markings at the airport. The pavement marking configurations of this area were appeared to be more complex for aircraft operations under low visibility conditions, particularly at night. To enhance aircraft operation safety, improvements to the marking configurations were needed.

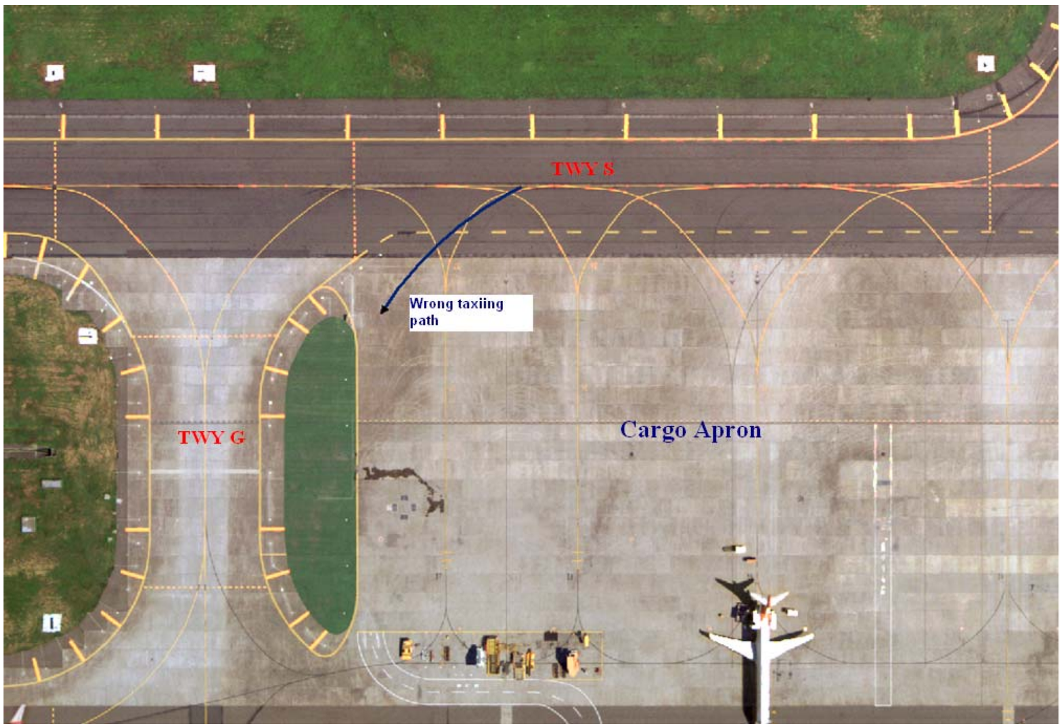

FIGURE 4c Before improvements at the intersection of TWY S, G, and cargo apron

Problem Solutions

Airfield visits were scheduled to identify possible reasons for the ground incidents as previously described. As shown in Figure 4c, the nose-wheel-lead-in lines for visual aids to cargo apron showed complex patterns (cross over each other). Such patterns of lead-in lines were originally designed to match the existing taxiway centerline. It was determined that these complex built-on markings were responsible for the pilots' confusion. It appeared that pilots might mistakenly take a left turn earlier, before moving to the intersection (Figure 4c). This was particularly critical at night or during low visibility. The span distance of lead-in lines between the apron and the Taxiway G was measured at 55 m. In addition, pavement markings crossed over with the neighboring line. From the eye positions of the pilots, such marking configurations were not significant enough in helping pilots distinguish the exact taxiing lead-in lines towards the Taxiway G.

To further minimize the possibility of confusion at the intersection of Taxiway S, G, and cargo apron, the following changes were done as part of the improvement project.

1. Existing nose-wheel-lead-in lines were replaced with offset nose-wheel lead-in lines. This offset marking pattern was designed to significantly separate two operation areas (e.g. cargo apron and intersection of TWY S and G) so that the taxiway centerline markings to Taxiway G and offset lead-in lines to cargo apron are well-defined. Pilots would not confuse the maneuvering positions while operating aircraft to this area. Offset lead-in lines were conducted in compliance with ICAO Aerodrome Design Manual Part 4, Section 2.3.5 *(2)*.
2. Place geographic position markings (surface indication signs) on the pavement surface and each offset nose-wheel lead-in line to assist pilots in observing the visual cues when making a left turn to the Taxiway G. Geographic position markings were installed in front of the intersection on the surfaces of the Taxiway S and G. This design was intended to help pilots identify the position of taxiing aircraft during low visibility conditions. It should be noted that the information of geographic position markings are mentioned in ICAO standards only for distinguishing runway entrance indication. However, specifications of geographic position markings on taxiways and aprons are described in the FAA AC 150/5430 standard *(4)*. Thus, the KHH engineers applied the FAA standard in the improvement project of pavement markings to make up the gap of geographic position markings information.

Comparisons between pre and post marking improvements at KHH are shown in Figure 4c-d. Since completion of the marking improvements at the intersection of Taxiway S and G in 2003, no wrong-turning incident has been reported to the Division of Operation. This improvement helped the KHH authority receive positive reactions from pilots with respect to the efforts on significant and well-defined marking improvements along the Taxiway S and at the intersection of Taxiway S and G.

FIGURE 4d After completion of marking improvements at the intersection of TWY S, G and entrance to cargo apron

PAVEMENT MARKING PROJECT ON INTERNATIONAL APRON

Statement of Problem

The international terminal buildings were open to service in 1997. The International apron consists of 12 aircraft parking stands suitable for B747, A330, A300, B767, B757, A320/A319/B737, MD-90/MD82, as well as other smaller aircraft. With increasing air travel demands at KHH, the arrival and departure aircraft strongly rely on the efficient and fast ground service of loading and unloading packages in order to connect to the next en-route flight plans on time. During peak hours ground crews will sometime park ground equipment (e.g. containers, transporters, trucks, etc.) in a disordered manner (because parking safety areas were not clearly defined at this point). A ground incident was reported in which a mobile equipment bumped against the frame surface of the parked airplane resulting in the cancellation of a scheduled flight. According to the markings review, apron safety zones that include apron safety lines, wing tip clearance lines, and equipment limit lines (equipment restraint lines) needed to be clearly defined and placed at all aprons.

Sensitivity Analysis and Problem Solutions

Based on field visits, ground incidents or unsafe movements can be prevented by clearly defining the restriction areas within the apron surfaces. The ground moving areas include service roads, safety zones, and equipment parking areas; they all require pavement markings to be defined as moving, parking, operations, loading and unloading areas. The specifications of apron safety lines have been documented by the ICAO Aerodrome Design Manual part 4, Section 2.3.20 *(2)*. In addition, the IATA Section 5.3.9 has also graphically illustrated the specifications of apron safety lines with figures *(3)*. Integrating both standards gave the KHH engineers good guidance to define apron safety zones for ground equipment movements. Equipment restraint lines were installed behind ground equipment and designed for restriction limit area during the push-off or head-in movement of an aircraft. Also such lines were intended to provide ground equipment with a safety stop area when making the final approach to the parked aircraft.

In advance of locating safety zone markings for aircraft and ground equipment movements, a sensitivity analysis was performed to ensure clear space between an aircraft and the nearest object (e.g. terminal buildings, service road, neighboring aircraft, etc.). The purpose of the sensitivity analysis is to examine the potential risks due to the relocation of the pavement markings and installation of new markings in the apron areas. Figure 5a shows the analysis results of restraint line installation for five categories of aircraft, B747, A330, B757, B737, and MD 90. The principle of the sensitivity analysis is to ensure that the minimum clearance of 7.5 m at each side of parked aircraft (aircraft's nose, both sides of wing tip, and vertical wing tip) to any adjacent object is maintained; otherwise compliant adjustments need to be made. As shown in Figure 5a, a horizontal clearance of 6.87 m from the B747's vertical wing tip to the edge of the service road was needed. However, this marking plan was in disagreement with the standards. Therefore, the front clear distance of 8.2 m (parameter A in Figure 5a) at the B747 aircraft parking stand was adjusted to 7.5m so that the horizontal distance of 6.87 m was increased to 7.77 m. This adjustment made the minimum clearance requirement in compliance with the ICAO standards at front and end sides of B747 aircraft.

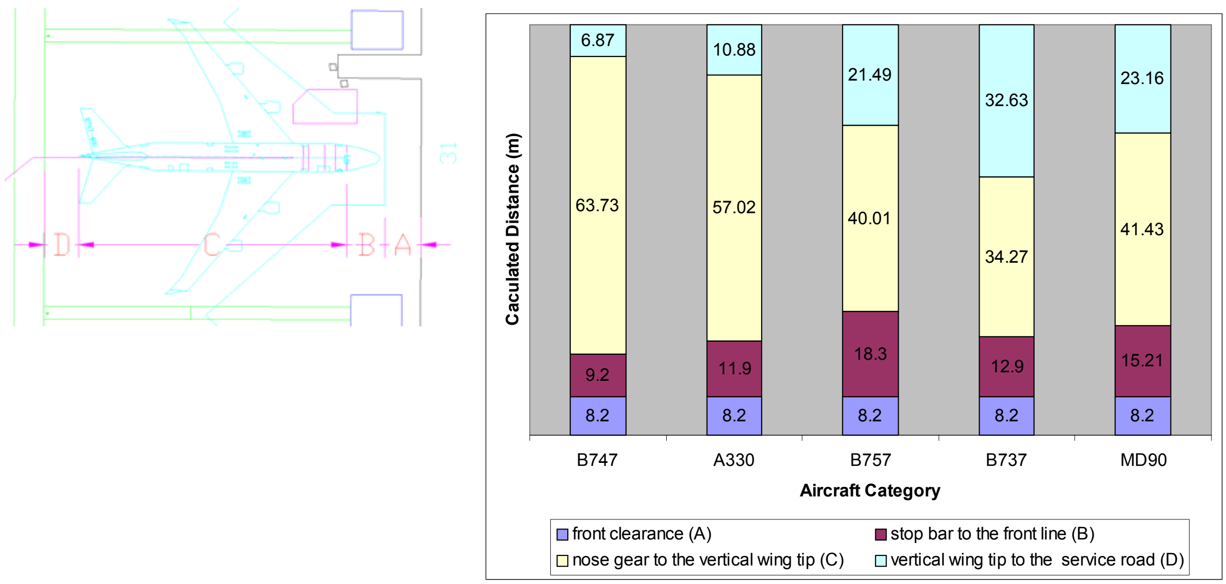

FIGURE 5a Sensitivity analysis for equipment restraint line installations in apron parking stands

After completion of restraint lines and other visual aid markings (e.g. geographic indication marking for each aircraft parking position), the safety zones in the international apron and other apron areas have been well defined and provide ground service employees with clear indications for loading and unloading areas (Figure 5b). Such marking enhancements not only can meet the amendment, but also help airport operators effectively execute apron safety policies.

FIGURE 5b Well-defined safety zones help increase apron management efficiency at KHH

PAVEMENT MARKING PROJECT ON DOMESTIC AND FAR-END APRONS

Statement of Problem

The far-end apron connection provides the taxiing paths for aircraft movements to and from the domestic apron (Figure 1). Between these two aprons, a service road was built across the apron areas. In addition to install apron safety markings, unclear movement path for ground vehicles and shorter clearances for safety zones were also reviewed in these apron areas. Figure 6a illustrates three identified issues related to safety concerns in aircraft operations and ground equipment movements.

1. The first issue was located at the aircraft movement interaction between the international apron stand #24 and domestic apron stand #18. Due to limited clearance between these two stands, only one aircraft was allowed to park at either #24 or #18 parking position (Figure 6a). In past years, this limitation decreased availability of parking positions and parking position assignment policies for arrival aircraft, particularly at peak hours.
2. The second issue was observed in the domestic apron area. Service road layout was not clearly planned for ground equipment movements. It was noticed that ground mobile equipment traveled through aircraft lead-in lines delivering cargo and other items (Figure 6a). Such situations created an unsafe operating environment. Installing a new service road in the domestic apron will be the priority used to address this issue. The challenging task was the limitations of existing geometric conditions (surrounding parking lots and other equipment parking areas) for future service road extension.
3. The third issue was identified to be shorter clearances between aircraft parking stands and the service road at the far-end apron (Figure 6a). Measured dimension of 5.8 m between the nose of the parked aircraft and the edge of the service road did not meet the minimum clearance of 7.5 m. Ground mobile equipment such as passenger stair equipment moving on the road could potentially intrude the safety zone and possibly hit the parked aircraft's nose under low visibility conditions or at night.

FIGURE 6a Identified issues in the far-end apron and domestic aprons

Sensitivity Analysis and Problem Solutions

To address these three identified issues, a marking improvement plan was proposed that included relocations of the existing service road 3.5 m south, building a new service road parallel to the existing road, and dimension rearrangements of existing lead-in lines in the domestic apron (Figure 6b). Prior to construction, a sensitivity analysis was initiated to 1) calculate the spans between maneuvering/parked aircraft and the nearest object, and 2) determine parking limitation information for different aircraft types to optimize utilizations of aircraft parking stands. The contents of the improvement plan are summarized as follows and illustrated in Figure 6b:

1. The existing parking lots for ground equipment between the far-end apron and domestic apron were removed to available spaces near by the domestic terminal. This allowed relocating the existing service road and building a new service road for ground equipment movements within the far-end apron and domestic apron areas.
2. The aircraft maneuvering boundary lines were created along the far-end and domestic aprons and a sensitivity analysis was carried out to ensure that the required wing tip clearance was kept.
3. To optimize the utilizations of parking positions, the existing lead-in lines in the domestic apron were rearranged to accommodate large wide-body aircraft operation at #24 stand and also allow parking a small aircraft (ATR72, Fokker 50, etc.) at #18 stand. This change will address the first issue and optimize the utilizations of parking stands in both international and domestic aprons.

4. The parking position metrics were developed to evaluate the clearances between two neighboring aircraft. This effort was used to assign the arriving aircraft a parking position with available parking stands based on the calculated clearances with respect to the parked aircraft type.

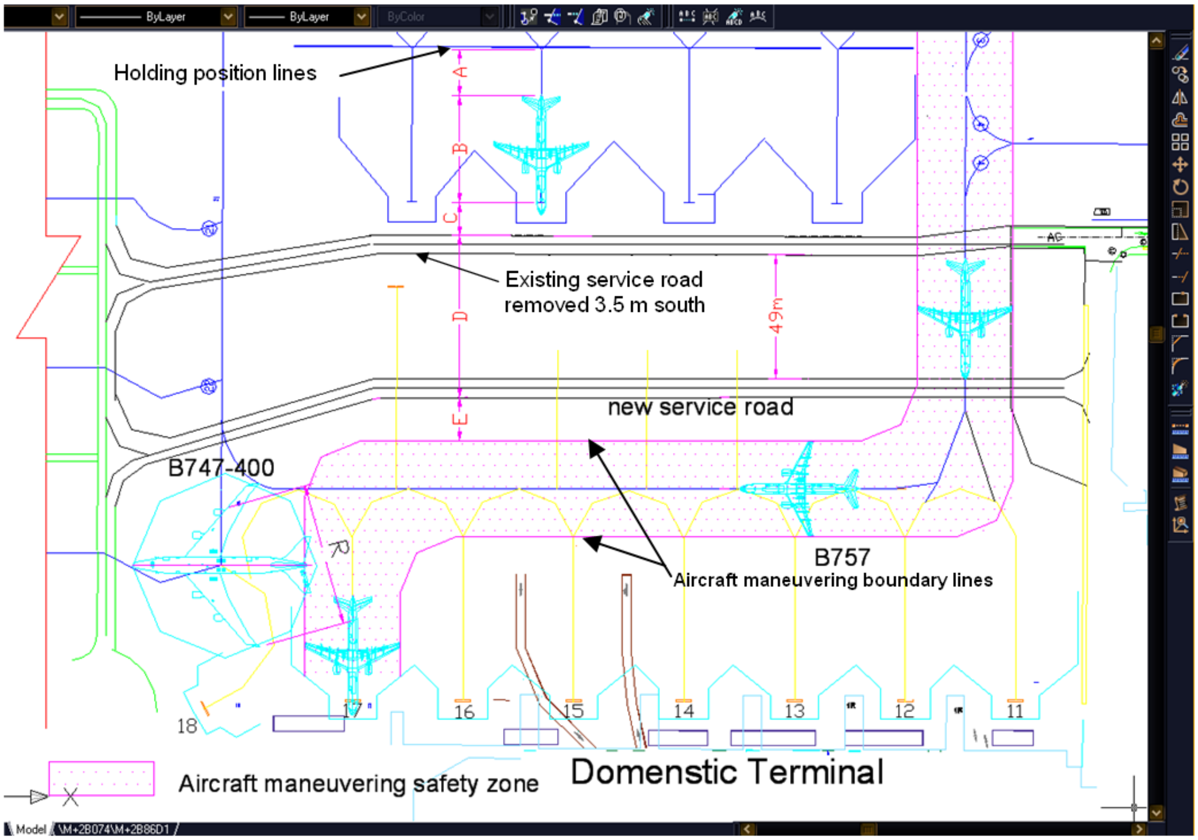

FIGURE 6b Simulation process of service road extension and marking relocations

During the sensitivity analysis, the nose gear path of a moving aircraft was assumed to be 1 m offset between the aircraft taxiing centerline used to model the critical scenarios for each aircraft category including A330, A300, B767, B757, B737, and MD90. This assumption is based on observations in the apron areas. Thus, the one-meter offset of taxiing path from the centerline could result in conservative estimates for the calculations of the wing tip clearance (parameter E in Figure 6b). In addition, in the far-end apron areas, the distance between the holding position lines to the taxiway centerline needed to be kept at least 47.5 m according to the ICAO. Under the principles of clearance limitations at both far-end and domestic aprons, a simulation was performed to determine allowable distances for each aircraft type during the processes of service road installations, and dimension rearrangements of lead-in lines. The criteria for a successful plan is that the calculated allowable distance between each aircraft's wing tip must be greater than the minimum clearance of 7.5 m; otherwise dimension adjustments of lead-in lines and service roads needed to be achieved. The calculated results are depicted in Figure 7.

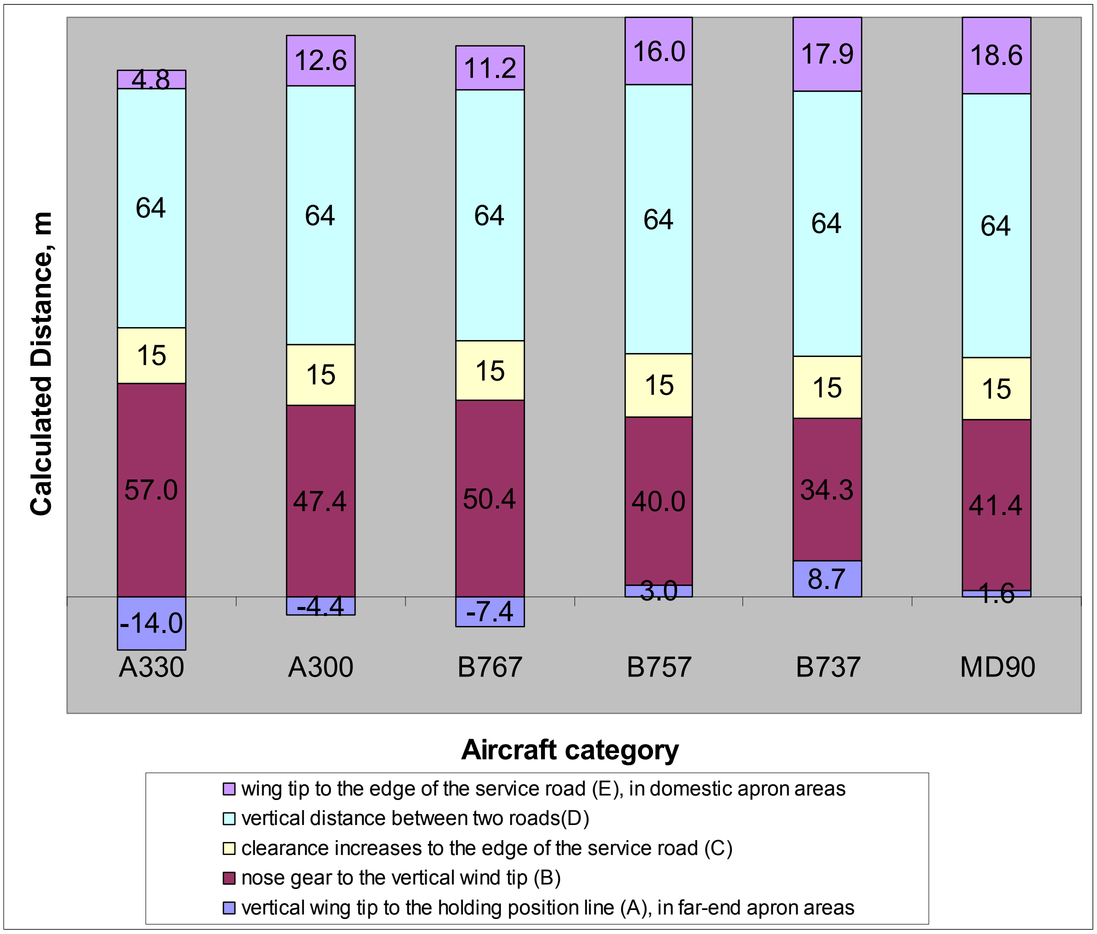

FIGURE 7 Sensitivity analysis for service road installations and aircraft movement path adjustments in the far-end and domestic apron areas

Note: parameters A, B, C, D, and E refer to Figure 6b

After relocation of the existing service in the far-end apron, the clearance distance between the nose of a parked aircraft and the edge of the service road was increased to 8 m. This design met the requirement. However, it was observed that the back edges of the B330, B300, and B767 aircraft exceeded the holding position line in the far-end apron. Thus, the allowed maximum demanding aircraft type was determined to be a B757 or other aircraft code D defined by the ICAO or aircraft design group IV defined by the FAA.

As part of the domestic apron marking improvement plan, the sensitivity analysis associated with aircraft parking position matrix computation was performed to determine the appropriateness of marking design work before construction. The purpose of the sensitivity analysis was to 1) calculate the clearance between the wing tip of the moving aircraft and the edge of new service road to ensure that the required clearance was in accordance with aviation standards, and 2) provide the aircraft parking position metrics to compute wing tip clearance changes as different type of aircraft stopped on the parking positions. Demanding aircraft should meet both wing tip clearance requirements at the moving path boundary envelopes and parking position metrics while being allowed to park at the assigned position. Through the analysis efforts in the domestic apron areas, the following results were obtained:

1. As shown in Figure 6b, the original demanding aircraft (aircraft type D) for parking # 18 stand was replaced with aircraft type C (group III by the FAA) such as ATR72, DASH8-300, Foker50, etc. This change allows large wide-body aircraft to park on at #24 apron and small propeller aircraft park on at #18 apron at the same time, making aircraft parking position assignments more flexible and effective.
2. Wing tip clearance calculations between the aircraft moving boundary line to the edge of the new service road were described in Figure 7 in the row of parameter E. It is observed that except an A330, other demanding aircraft types meet the requirements of minimum clearance, 7.5m. However, such demanding aircraft should be further evaluated with results of the aircraft parking position metrics depicted in Table 3 to determine the required aircraft types allowed in the domestic apron.
3. In Table 3, after dimension adjustments in the domestic apron, no aircraft is allowed to park near a B767 aircraft due to the effect of its longer wing span on reducing the clearance. Another wide-body aircraft, A300-600, can only park next to a neighboring B737 aircraft or smaller. An ATR72 or smaller aircraft is allowed to park next to the B757 aircraft. Other aircraft B737, MD90, and ATR72 provide more availability and spaces to park with demanding aircraft as indicated in Table 3.
4. The information shown in Table 3 is very practical for airport operators at KHH to assign arrival aircraft parking positions using the clearance relation between parked aircraft and arriving aircraft. For example, when a MD90 aircraft is traveling to the domestic terminal, airport operators can assign a parking position adjacent to B737, MD 90, ATR 72, or other smaller aircraft parked in the domestic apron areas.

The results of the sensitivity analysis and aircraft parking position metrics were proposed to the KHH authorities for policy-making use. The proposed improvement project was completed as of August 2004. Ground mobile equipment can follow the built-on service roads towards the far-end and domestic aprons without traveling through the aircraft taxiing path or lead-in lines. In addition, dimension adjustments of lead-in lines allow airport operators more spaces to assign aircraft parking positions for arriving aircraft based on the aircraft parking position metrics information. The clearance requirement between the aircraft and the nearest object was reviewed, adjusted, and kept in compliance with aviation standards, resulting in a safer operation environment for aircraft maneuverings and ground mobile equipment movements.

TABLE 3 Calculated wing tip distances for aircraft parking position metrics

Aircraft Information						
Aircraft type	A300	B767	B757	B737	MD90	ATR72
Wing span (m)	44.84	54.94	47.33	34.3	32.85	27.5
Aircraft parking position centerline dimension, m	43.6 m					

Aircraft parking position metrics: Calculated wing tip distance between two neighboring aircraft, (m)						
	A300	B767	B757	B737	MD90	ATR72
A300	-2.48	-12.58	-4.97	8.06	9.51	14.86
B767	-12.58	-22.68	-15.07	-2.04	-0.59	4.76
B757	-4.97	-15.07	-7.46	5.57	7.02	12.37
B737	8.06	-2.04	5.57	18.6	20.05	25.4
MD90	9.51	-0.59	7.02	20.05	21.5	26.85
ATR72	14.86	4.76	12.37	25.4	26.85	32.2

Note: The allowed wing tip clearance is 7.5 m according to the ICAO and IATA standards

CONCLUSIONS

The updated or improved strategies for pavement markings in compliance with ICAO standards were presented in this paper. Through a comprehensive review of pavement markings, the updated or improved configurations of pavement markings at KHH meet the ICAO standards, address previously identified issues, as well as increase the aircraft operation safety and ground movement safety. Since completion of pavement marking enhancements in August of 2004, no ground incident related to unclear pavement markings has been reported to the KHH authorities. The two-year involvements in the projects of marking improvements at KHH feature the following conclusions and recommendations:

1. Based on assessments of the sensitivity analysis, the relocation of aiming point markings aligned with the PAPI system can meet the ICAO standards and assist pilots in clearly using visual cues when descending the aircraft to the landing runway.
2. New pavement markings along the Taxiway S help pilots distinguish the landing runway and provide pilots with appropriate visual aids when traveling onto the Taxiway S towards the assigned aprons.
3. Offset nose-wheel-lead-in markings associated with the geographic indication marking installations at the intersection of Taxiway S and G works better in preventing the maneuvering aircraft from taking a wrong turn to the cargo apron.

4. Based on results of a sensitivity analysis, after completion of the marking project in the far-end apron areas, only B757 or smaller aircraft are allowed to park in these areas.
5. Apron safety zone markings were applied in international, far-end, cargo, and domestic apron areas. As observed at apron areas, equipment restraint lines serve a safety boundary for all ground equipment movements to make a safe stop in advance of the final approach to the parked aircraft. The results of sensitivity analysis provide suggestions to the KHH authorities to adjust the stop bar location of B747 aircraft in order to meet the minimum clearance requirement.
6. The pavement markings including lead-in lines and service roads were redesigned to optimize the utilizations of parking positions among the far-end and domestic apron areas.
7. When assigning arriving aircraft parking positions in the domestic apron, Table 3 depicts the relations of wing tip clearance between two neighboring parked aircraft. KHH operators can perform parking position assignments for arriving aircraft using the information shown in Table 3.

The ideas and strategies applied at Kaohsiung International Airport regarding markings issues are discussed along with issues that lead to the changes. It is important to understand how the airport authorities dealt with those issues.

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