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ORIGINAL ARTICLE

Analysis of Incentive Mechanism for Availability Payment System applied to Highway PPP Projects

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Abstract**:** Availability Payments (A/P) are provided to private sector service providers for providing access to infrastructure services such as highways in a safe, stable, user-friendly manner. One of the characteristics of an A/P system is that it is accompanied by a payment adjustment mechanism. The authors propose a formula model using performance indicators to improve the payment adjustment mechanism, and indicate how to regulate the optimal payment deduction ratio while considering the principal-agent problem. In addition, the payment adjustment mechanism and proposed formula is tested against data on American highway PPP projects.

Keywords: highway PPP project, availability payment, payment adjustment mechanism, agency slack

1. Introduction

1.1 Background

On many recent highway Public-Private Partnership (PPP) projects around the world, various types of payment systems are applied to enhance the quality of highway services, and the efficiency of concessionaire performance in carrying out operation & maintenance. Of these payment systems, the Availability Payment (A/P) system based on the concessionaire's ability to provide available highway roads to users has established itself as a major payment system. A/P systems have been increasingly applied to DBFOM (Design, Build, Finance, Operation, Maintenance） projects in the U.S. (U.S. DOT, 2016), DBFO projects in the UK (Nigel C. Lewis, 2008) among others.

In recent highway PPP projects in the U.S., there exist two types of funding. One is based on toll revenues from traffic users. The other is based on A/Ps from public funds. Highway concession contracts with an A/P system have been realized in DBFOM and DBFM projects in the U.S..

Evaluation of the Toll Revenue funding system applied to some highway concession projects in the early 2000s depends upon toll income from traffic users. However, complex economic risks make it difficult to predict user volume and traffic, posing a challenge for accurate revenue forecasting. As a result, investors are apt to hedge the risk of traffic demand and toll income, and are favorable towards

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obtaining stable income, irrespective of economic risks. A/P systems are becoming increasingly popular, with just over half (9/17) of the PPP highway projects in the U.S. since 2009 utilizing A/P systems (U.S. DOT, 2016).

1.2 Characteristics of an A/P System

If the project is a tolled highway road, the public sector retains revenues from tolls as well as the risk that revenues will not reach forecasted levels. The public sector chooses to utilize an A/P system for several reasons, such as to retain risk when the private sector demands too high of a risk premium on traffic risk, to encourage more bids by lowering this risk, and to alleviate public concerns over control of toll rates by the private sector.

With an A/P system, to determine the payment amount, private sector bidders submit bids based on the annual Maximum A/P (MAP). Based on the agreement between the public sector and the concessionaire who wins the bid, the public sector makes periodic payments to the concessionaire on the condition that the highway facility meets performance-based specifications.

However, if the concessionaire cannot realize the requirements for availability, payments are adjusted or deducted from the MAP in accordance with the formula agreed between the public sector and the concessionaire in advance. This payment is based on the performance for availability and this adjustment mechanism is one of the characteristics of A/Ps.

According to the "Availability Payment Concessions Public-Private Partnerships Model Contract Guide" issued by Federal Highway Administration, A/P adjustments are attributed to Lane-Closures or Availability Faults led by Unavailability Events such as vehicle crashes, roadway debris, guardrail hits, potholes, roadway shoulder wash-outs, roadway cave-ins, natural disasters/events/storms, incidents/events resulting from human interactions, and other unforeseen events. For Availability Faults that are not resolved within the permitted time, adjustments or deductions commence from the time of occurrence.

Furthermore, adjustments or deductions for Operation & Maintenance are conducted in the event of O&M violations or O&M non-compliance. These calculations also commence from the time of occurrence if failure of the asset is not resolved within the permitted time.

1.3 Objective

Typically, incentives for the concessionaire should be related to facilitating the objective of asset management regulated by the public sector. Degradation of a concessionaire's performance leads not only to payment deductions for the concessionaire, but to lower quality of services and/or facilities.

If an incident/accident leading to Unavailability occurs, a concessionaire generally tries to shorten the period of Unavailability to reduce the A/P deduction amount from and to meet the public sector requirements. However, if the payment deduction ratio is too small, the concessionaire accepts the payment deduction without having to consider additional costing to open a lane as quickly as possible. This is a kind of moral hazard by a concessionaire referred to as "agency-slack" (Chunhui Xu, 2011). Conversely, if the deduction ratio is too large, the concessionaire suffers irrecoverable losses, leading to excessive risk and zero private-sector participation.

Furthermore, the occurrence of Unavailability Events may differ in accordance with the condition of the roads, the quality of maintenance, the state of traffic usage, and other factors. Therefore, a payment adjustment mechanism should be regulated to consider these conditions.

This paper focuses on the payment adjustment mechanism of an A/P system for Unavailability (Lane-closure, Availability Fault) and the conditions on incentivizing a concessionaire to perform operation and maintenance services from the principal (public sector) – agent (private sector) problem perspective. The effect of the proposed model is also tested to assess and compare various actual payment adjustment mechanisms that are utilized by highway PPP projects in the U.S.

From the principal-agent problem perspective, the authors propose a feasible formula model using indicators to assess the adjustment mechanism of an A/P system and indicate that there exists an optimizing deduction ratio for the public sector to give the concessionaire an incentive to shorten the period of Unavailability. The concessionaire can take optimizing actions in accordance with the deduction ratio regulated by the public sector.

1.4 Previous Studies

Previous studies and research on A/P systems have proposed optimizing design models (Sharma, 2012), and have focused on individual projects such as the A13 Thames Gateway in the UK, a DBFO project (Lewis, 2008). The Japan Society of Civil Engineers' Construction Management Committee has also produced a report on Highway Maintenance of PFI projects in Portsmouth and Sheffield in the UK (2014). Recently, Hirashima and Ozawa (2016) arranged A/P systems applied to the I-595 Highway in the U.S. (a PPP project). As for research on road maintenance work, Soliño (2015) produced an optimizing model for payment mechanisms on road management using "road capacity availability" as one of its performance indicators.

2. Formula of Payment Adjustment Mechanisms for A/P Systems

2.1 Payment Adjustment Mechanisms and Concessionaire's Actions

From the position of the highway owner, the public sector tries to provide stable public services to traffic users. If an incident leading to Unavailability occurs, the priority becomes shortening the period of Unavailability and to open the road as quickly as possible. In this case, a variation of payment adjustment is set forth by the public sector giving the concessionaire great influence on the optimizing balance between the amount of payment adjustment and additional costs. As for the concessionaire, it is most reasonable and profitable to minimize losses (payment adjustment plus additional cost). The private sector's desire to minimize losses meets directly with the public sector's benefits, which are dependent upon its ability to minimizing the period of Unavailability.

However, if a concessionaire's agency-slack occurs, the public sector cannot shorten the period of Unavailability. Therefore, conditions on preventing the concessionaire from causing agency-slack and incentivizing the concessionaire should be analyzed from the perspective of the principal-agent problem.

Furthermore, if the risk occurrence probability leading to payment deductions is too large, the concessionaire's action to participate in providing services will be haltered. Considering this situation, an appropriate method of regulating the payment adjustment mechanism is proposed.

2.2 Formula of Payment Adjustment Mechanisms for Unavailability

To assess the payment adjustment mechanisms, some basic conditions are regulated as follows.

Suppose the maximum hourly income (MAP) of a concessionaire as W_1 and typical cost C_0 as $k_1 \times W_1$.

$$C_0 = k_1 \times W_1 \qquad \cdots\cdots (2.1)$$

Hourly payment deductions W_2 due to Unavailability can be indicated as follows, using

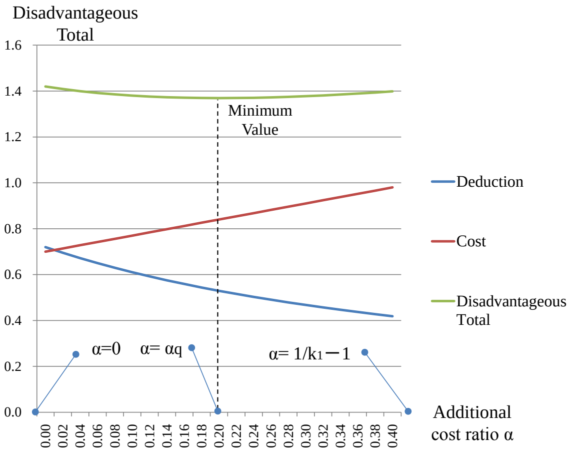

Fig. 2.1 Relationship between additional cost ratio and Disadvantageous Total

indicator b as the payment deduction ratio.

$$W_2 = b \times W_1 \qquad \cdot\cdot\cdot\cdot(2.2)$$

A concessionaire with efficiency E is supposed to enhance the performance Eα using the additional cost ratio α, and as a result, the period of lane-closure is shortened and the deduction amount can be minimized. Hence, the hourly amount of deduction W_3 can be calculated as:

$$W_3 = W_2/(1+E\alpha) \qquad \cdot\cdot\cdot\cdot(2.3)$$

If lane-closures occur, a concessionaire's profit will hinge on the ability to minimize the total additional cost incurred to open the road, as well as the payment deduction amount. The authors term this the "Disadvantageous Total" Q and can be represented as the following equation:

$$Q = C_0 \times (1+\alpha) + W_2 / (1+E\alpha)$$
$$= W_1 \times \{ k_1 \times (1+\alpha) + b / (1+E\alpha)\} \quad \cdot\cdot\cdot(2.4)$$

Here, α_q gives the minimum Q, which can be obtained through differential calculus applied to (2.4), leading to:

$$dQ / d\alpha = W_1 \times \{ k_1 - b \times E / (1+E\alpha)^2 \} = 0$$
$$\alpha_q = \sqrt{(b / k_1 E)} - 1 / E \qquad \cdot\cdot\cdot\cdot(2.5)$$

Here, maximum hourly costs are supposed to equal hourly income, and thus the maximum additional cost ratio can be calculated as $(1/k_1\text{-}1)$. The concessionaire's action will differ according to the value of α_q.

If α_q is greater than $(1/k_1\text{-}1)$, the minimum Disadvantageous Total Q is realized at the point where α_q is $(1/k_1\text{-}1)$, which is to say, the concessionaire conducts the best performance investing maximum additional costs. If α_q is smaller than zero, the minimum Disadvantageous Total Q is realized at the point where α_q is zero and the concessionaire does not incur any additional costs. If α_q exists between zero and $(1/k_1\text{-}1)$, there exists an optimizing point for the concessionaire that holds the Disadvantageous Total Q to the minimum. As a result, the concessionaire will incur additional costs up to the optimizing point of α_q. Fig. 2.1 shows the relationship between α_q and the Disadvantageous Total Q, and the following Eqs. (2.6)-(2.8) also show the concessionaire's actions in accordance with α_q values.

The concessionaire incurs maximum additional costs at:

$$1/k_1 - 1 \leqq \alpha_q \qquad \cdot\cdot\cdot\cdot(2.6)$$

The concessionaire incurs additional costs up to the optimizing point when:

$$0 < \alpha_q < 1/k_1 - 1 \qquad \cdot\cdot\cdot\cdot(2.7)$$

The concessionaire does not incur any additional costs when:

$$\alpha_q \leqq 0 \qquad \cdot\cdot\cdot\cdot(2.8)$$

The incentive boundary is regulated to incentivize the concessionaire to incur additional costs to improve performance. The slack boundary is regulated to avoid agency-slack by the concessionaire.

Pursuantly, a payment deduction ratio b is solved from Eqs. (2.6)-(2.8).

The concessionaire incurs maximum additional costs when:

$$b \geqq \{\sqrt{(E / k_1)} - \sqrt{(k_1 \cdot E)} + \sqrt{(k_1 / E)}\}^2 \qquad \cdot\cdot(2.9)$$

The concessionaire incurs additional costs up to the optimizing point when:

$$k_1 / E < b < \{\sqrt{(E / k_1)} - \sqrt{(k_1 \cdot E)} + \sqrt{(k_1 / E)}\}^2 \qquad \cdot\cdot\cdot\cdot\ (2.10)$$

The concessionaire does not incur any additional costs when:

$b \leqq k_1 / E$ ・・・・(2.11)

Furthermore, the participation boundary for of projects should also be considered. If too many incidents/accidents leading to lane-closures occur, the concessionaire will be doomed to suffer losses from frequent payment deductions. The relationship between the amount of payment deductions and the probability of incident/accident occurrence must be considered.

The hourly typical profit R can be indicated as follows, considering (2.1):

$R = (1 - k_1) \times W_1$ ・・・・(2.12)

Marginal profit R_{min} can be indicated as:

$R_{min} = k_2 \times (1 - k_1) \times W_1$ ・・・・(2.13)

Here, k_2 indicates the factor for marginal profit to the typical profit R.

Maximum loss for the concessionaire is calculated when incidents leading to lane-closures occur by the hourly occurrence probability of *n*, and when the maximum Disadvantageous Total Q_1 is realized at point $\alpha=0$ (the most disadvantageous situation for a concessionaire). Q_1 can be obtained as follows by using Eq. (2.2):

$Q_1 = b \times W_1 \times n$ ・・・・(2.14)

Conditions for a concessionaire's participation will be that the value of the maximum Disadvantageous Total Q_1 is smaller than the marginal profit, using Eq. (2.12)- (2.14), and is expressed as:

From $R - Q_1 \geqq R_{min}$,

$b \leqq (1 - k_2) \times (1 - k_1) / n$ ・・・・(2.15)

2.3 Concessionaire's Actions and Public Sector Benefits

As described in the previous section, maximizing the profit for a concessionaire is equal to minimizing the "Disadvantageous Total Q". It is indicated as Eq. (2.4) and the line of " Disadvantageous Total " in Fig. 2.1 indicates it.

$Q = C_0 \times (1+\alpha) + W_2 / (1+E\alpha)$

$= W_1 \times \{k_1 \times (1+\alpha) + b / (1+E\alpha)\}$ ・・・・(2.4)

On the other hand, the public sector's benefit is dependent upon its ability to minimize the period of Unavailability, which can be considered equal to the concessionaire's minimized payment deduction amount, that is, maximizing $E\alpha$. The public sector's benefit is parallel to the "Deduction" line in Fig. 2.1.

Furthermore, if *b* is too large, the concessionaire suffers a loss and the public sector takes the risk of no one participating in the project. Therefore, the condition of Eq. (2.15) is required.

Here, the concessionaire's profit is defined as W_1-Q, so the profit ratio Ia (= $(W_1-Q) / W_1$) can be formulated as Eq. (2.16). The public sector's benefit Ip (= $(W_2 - W_3) / W_2$) can be formulated as Eq. (2.17).

$Ia = 1 - \{k_1 \times (1+\alpha) + b / (1+E\alpha)\}$ ・・・・(2.16)

$Ip = 1 - 1 / (1+E\alpha)$ ・・・・(2.17)

Here, if $b \leqq k_1 / E$, then $\alpha=0$ (Slack zone)

if $k_1 / E \leqq b \leqq \{\sqrt{(E/k_1)} - \sqrt{(k_1 \cdot E)} + \sqrt{(k_1 / E)}\}^2$, then $\alpha = \alpha_q = \sqrt{(b / k_1 \cdot E)} - 1 / E$,

(Moderate performance zone)

if $\{\sqrt{(E/k_1)} - \sqrt{(k_1 \cdot E)} + \sqrt{(k_1 / E)}\}^2 \leqq b \leqq (1 - k_2) \times (1 - k_1) / n$, then $\alpha = 1/k_1 - 1$,

(Optimal Performance zone)

if $b > (1 - k_2) \times (1 - k_1) / n$, a concessionaire suffers loss. (Shortfall zone)

In addition, a concessionaire can re-estimate the MAP and come up with a newly estimated income W by using the ratio of K and adding typical income values W_1, as follows:

$W \geqq K \times W_1$

$= \{k_1 + k_2 \times (1 - k_1) + n \times b\} \times W_1$ ・・・・(2.18)

Based on the equations above, profit and benefit ratios for concessionaires and public sector owners can be arranged according to payment deduction ratios b, as illustrated in Fig. 2.2. Supposing typical

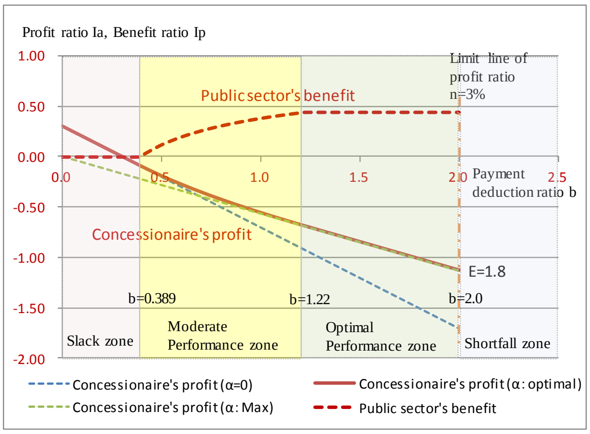

Fig. 2.2 concessionaire and public sector's profit and benefit ratio

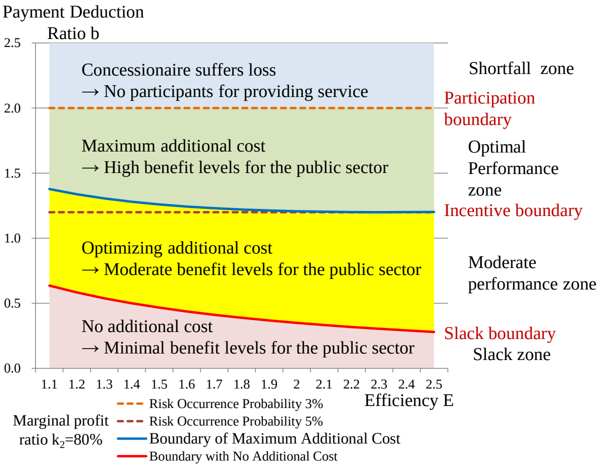

Fig. 2.4 concessionaire’s action pattern

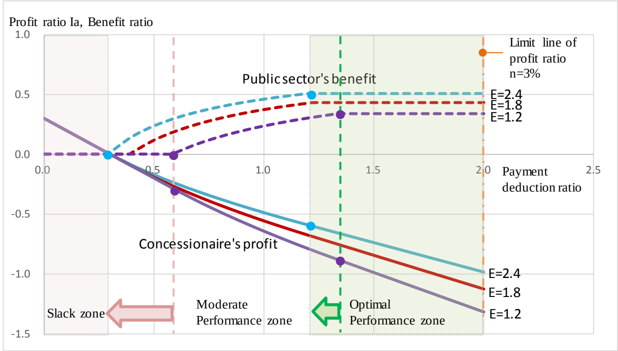

Fig. 2.3 concessionaire’s profit and public sector’s benefit in accordance with E

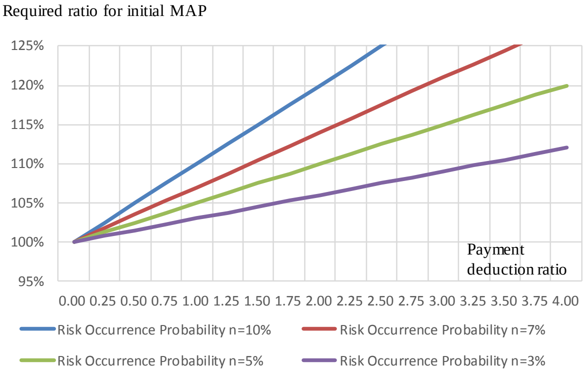

Fig. 2.5 required ratio for initial MAP in accordance with risk occurrence probability

cost ratios at a value of k_1=0.7 and the concessionaire’s efficiency of E=1.8, risk occurrence probability is at n=3% and the concessionaire’s marginal profit ratio would be k_2=0.8. The results are as follows.

b≦0.389 : The concessionaire may not incur any additional costs. → A shortened period of Unavailability may not be expected, so the public sector’s benefits may not be obtained. (Slack zone)

0.389＜b＜1.22 : The concessionaire tries to incur additional costs to obtain a moderate level of profits → A shortened period of Unavailability possibly leads to a moderate level of public sector benefits. (Moderate performance zone)

1.22≦b≦2.0 : The concessionaire tries to incur additional costs to obtain maximum profit.→ A shortened period of Unavailability possibly leads to maximum benefits for the public sector. (Optimal performance zone)

2.0＜b : The concessionaire suffers a loss. → The public sector is exposed to the risk that no one will participate in the project, or that the newly estimated MAP becomes bigger than the initially expected MAP. (Shortfall zone)

Fig.2.3 shows the relationship between the payment deduction ratio and a) a concessionaire’s profit or b) the public sector’s benefit, due to concessionaire efficiency. Highly efficient concessionaires bring about higher benefits for the public sector while increasing their profit (by minimizing their deductions) which corresponds to a larger optimal performance zone area and a smaller slack zone area.

Fig. 2.4 shows the concessionaire's action patterns and the benefit levels for the public sector in accordance with the relationship between the payment deduction ratio and the concessionaire's efficiency E. The payment deduction ratio has three boundaries which generate four zones. The blue line which indicates the incentive boundary is represented by Eq. (2.9), and the red line indicating the slack boundary is represented in Eq. (2.11).

The dotted line indicating the participation boundary is represented in Eq. (2.15). If we assume an incident occurrence probability of n=3%, the payment deduction ratio b should be equal to or less than 2.0 (the orange dotted line). If the incident occurrence probability rises to n=5%, the payment deduction ratio b should be equal to or less than 1.2 (the purple dotted line).

Supposing a concessionaire's marginal profit ratio is $k_2 = 1.0$ (100%), the newly required ratio for initial MAP is calculated as:

$$\begin{aligned} K &= k_1 + k_2 \times (1 - k_1) + n \times b \\ &= 0.7 + 1.0 \times (1 - 0.7) + n \times b = 1.0 + n \times b \qquad (2.19) \end{aligned}$$

Fig. 2.5 shows the relationship between the payment deduction ratio and the required ratio for the initial MAP due to differences in the level of risk occurrence probability. The higher the risk occurrence probability becomes, the required MAP ratio for obtaining a marginal profit ratio of $k_2=1.0$ (100%) also increases, consequently placing pressure on public sector owners that internally set the MAP at a level to maximize value for money within their own budgetary restrictions and cost boundaries.

3. Case Studies of Highway Projects in the U.S.

In this section, characteristics of payment adjustment mechanisms for 6 (six) highway PPP projects in the U.S. that utilize A/Ps are compared and analyzed with the definitions outlined in the previous section.

3.1 Analysis of Existing Payment Adjustment Mechanisms on Highway PPP Projects

3.1.1 The I-595 (Florida)

The I-595 highway is the first such PPP project in the U.S. to apply a payment adjustment mechanism for unavailability within an A/P system.

Payment adjustments are regulated within the contract agreement of the project. The adjustment amount $QUA_{q,y}$ for Unavailability is calculated as follows:

$$QUA_{q,y} = \sum_{\text{hour } h=1}^{hq} HUA_h \quad \cdots\cdot (3.1)$$

$$HUA_h = \sum_{\text{Segments}=1}^{n} [HUF_{h,s} \times SWF_{h,s} \times TWF_{h,s}] \times \frac{MAP_y}{(365 \times 24)} \quad \cdots\cdot (3.2)$$

Where, hourly (h) and segmented (s) units are applied to: HUA_h: Hourly Unavailability Adjustment; $HUF_{h,s}$: Hourly Unavailability Factor; $SWF_{h,s}$: Segment Weighting Factor; $TWF_{h,s}$: Time Weighting Factor; and MAP_y: Maximum Availability Payment in year "y".

The payment deduction ratio is calculated in accordance with Eq.(3.2) and factors regulated in the contract agreement are listed in Table 3.1. The colored categories are due to the concessionaire's action pattern indicated in Fig. 2.4. Referring to Table 3.1, the limit of the risk occurrence probability can be calculated on the condition that the concessionaire's marginal profit ratio is $k_2=0.8$. For example, if an incident which belongs to Unavailability classification G on Table 3.1 occurs during weekday high priority hours at Segment 1-4, the payment deduction ratio is regulated as $b=2.4$. Thus the risk occurrence probability is calculated as $n = 0.025$ from Eq. (2.15). This means that if incidents with Unavailability classification G occur at a rate of 2.5% of the total within the service

Table 3.1 payment deduction ratio on I-595

		Payment deduction ratio by the combination of factors						
		Hourly Unavailability Factor						
	Factor	A	B	C	D	E	F	G
		0.1	0.2	0.4	0.6	0.7	0.8	1
■ Segment 1～4（Segment Weighting Factor 0.2）								
High Priority Hours 6:00～9:00, 16:00～19:00	12	-	-	0.96	1.44	1.68	1.92	2.40
Mid Priority Hours 9:00～16:00, 19:00～22:00	6	-	-	0.48	0.72	0.84	0.96	1.20
Low Priority Hours 22:00～6:00	2	0.04	0.08	0.16	0.24	0.28	0.32	0.40
Unavailability（3 lane part）	6:00-22:00				1lane		2 lanes	3 lanes
	22:00-6:00	1lane	2 lanes					3 lanes
■ Segment 5（Segment Weighting Factor 0.2）								
High Priority Hours	20	-	-	-	2.40	-	3.20	4.00
Mid Priority Hours	6	-	-	-	0.72	-	0.96	1.20
Low Priority Hours	1	-	-	0.08	0.12	-	0.16	0.20

Table 3.2 payment deduction ratio on I-4

		Payment deduction ratio by the combination of factors						
		Hourly Unavailability Factor						
	Factor	A	B	C	D	E	F	G
		0.1	0.2	0.4	0.6	0.7	0.8	1.0
■ Segment 1～4（Segment Weighting Factor 0.125）								
High Priority Hours 6:00～9:00, 16:00～19:00	12	-	-	0.60	0.90	1.05	1.20	1.50
Mid Priority Hours 9:00～16:00, 19:00～22:00	6	-	-	0.30	0.45	0.53	0.60	0.75
Low Priority Hours 22:00～6:00	2	0.03	0.05	0.10	0.15	0.18	0.20	0.25
Unavailability（3 lane part）	6:00-22:00				1 lane		2 lanes	3 lanes
	22:00-6:00		1 lane	2 lanes				3 lanes
■ Segment 5（Segment Weighting Factor 0.125）								
High Priority Hours	20	-	-	-	-	-	2.00	2.50
Mid Priority Hours	6	-	-	-	-	-	0.60	0.75
Low Priority Hours	1	-	-	-	-	0.09	0.10	0.13

Table 3.3 payment deduction ratio on I-69

		Payment deduction ratio by the factors		
		Unavailability Type Factor（T）		
		0.25	0.75	1.0
Segment A	Factor（S）	0.6		
Type of Day	Factor (D)	0.003162		
Unavailability Period	Factor(P)			
6:00～9:00	0.35	0.485	1.454	1.939
9:00～16:00	0.1	0.059	0.178	0.237
16:00～19:00	0.35	0.485	1.454	1.939
19:00～22:00	0.1	0.138	0.415	0.554
22:00～6:00	0.1	0.052	0.156	0.208
Number of closed lanes		1	2	3

Table 3.4 payment deduction ratio on East End

		Payment deduction ratio by the combination of factors				
		Unavailability Type Factor（T）				
		0.35	0.65	0.75	0.85	1.0
Segment A	Factor（S）	0.45				
Type of Day	Factor (D)	0.003162				
Unavailability Period	Factor(P)					
6:00～11:00	0.3	0.262	0.486	0.561	0.636	0.748
11:00～15:00	0.2	0.218	0.405	0.467	0.530	0.623
15:00～19:00	0.3	0.327	0.608	0.701	0.795	0.935
19:00～22:00	0.15	0.218	0.405	0.467	0.530	0.623
22:00～6:00	0.05	0.027	0.051	0.058	0.066	0.078
Lanes available (2 lanes in one direction)		2+1	1+1	2+0	1+0	0+0

Table 3.5 payment deduction ratio on Presidio

Southbound / Weekdays	Unavailability Factors = Payment deduction ratio				
number of closed lanes	1	2	3	4	5
Segments 5 lanes in each direction					
6:00～7:00	0.070	0.260	0.460	1.450	12.000
7:00～11:00	0.100	0.390	0.690	2.160	12.000
11:00～21:00	0.070	0.260	0.460	1.450	12.000
21:00～6:00	0.020	0.060	0.100	0.320	6.200
Segments 3 lanes in each direction					
6:00～7:00	0.120	0.430	12.000	-	-
7:00～11:00	0.180	0.640	12.000	-	-
11:00～21:00	0.120	0.430	12.000	-	-
21:00～6:00	0.030	0.100	5.030	-	-

Table 3.6 payment deduction ratio on Portsmouth

Mainline	Unavailability Deduction ($)		Payment deduction ratio	
number of closed lanes	1	2	1	2
Hour	2,955	$/h		
6:00～9:00	2,000	8,000	0.677	2.707
9:00～15:00	1,500	6,000	0.508	2.030
15:00～18:00	2,000	8,000	0.677	2.707
18:00～21:00	1,000	4,000	0.338	1.354
21:00～5:00	0	4,000	0.000	1.354
5:00～6:00	1,000	4,000	0.338	1.354

duration, the profit of a concessionaire falls below the limit (80%).

3.1.2 The I-4 (Florida)

Table 3.2 lists the results of the mechanism applied to the I-4, which fundamentally uses the same mechanism as the I-595.

3.1.3 The I-69 (Indiana)

Here we examine the payment adjustment mechanism for unavailability applied to the I-69. The Unavailability Adjustment for a single Unavailability Event (UA_e) is the product of factors defined by the Segment Factor (S), the Type of Day Factor (D), the Unavailability Period Factor (P), the number of lanes closed (T), the duration of the Unavailability Event (t) and the sum of the duration of Unavailability Periods during which the Unavailability Event occurred (H), as follows:

$$QUA_{q,y} = \sum_{e=1}^{n} UAe \quad \cdot\cdot\cdot\cdot(3.3)$$

$$UAe = MAPy\times S\times D\times P\times T\times (t/H) \quad \cdot\cdot\cdot\cdot(3.4)$$

Here, considering the converted hourly payment and payment deduction ratio b for hourly Unavailability, ratio b for 3-lane closures on Segment A from 7 to 8 AM on a weekday can be calculated as follows:

$$b = 0.6\times 0.003162\times 0.35\times 1.0\times (1/3)\times (365\times 24)$$
$$= 1.939$$

Table 3.3 lists the factors and the colored categories indicate action patterns of a concessionaire with E=1.8 as indicated in Fig. 2.4.

3.1.4 The East End Crossing (Indiana)

The payment adjustment mechanism for Unavailability applied to the East End Crossing is examined and outlined in Table 3.4. The fundamental mechanism is the same as the I-69 and can be indicated through Eqs. (3.3) and (3.4).

3.1.5 The Presidio Parkway (California)

The payment adjustment mechanism for Unavailability applied to the Presidio Parkway is examined. The Unavailability Factors ($UF_{h,td}$) in Eq. (3.6) are indicated in accordance with the direction (southbound or northbound), the number of closed lanes, and the type of day. Table 3.5 shows the Unavailability Factors on the southbound roadway on a peak day.

$$QUA_{q,y} = \sum_{e=1}^{n} UAe \qquad \cdot\cdot\cdot\cdot(3.5)$$

$$UA_e = \sum_{h=1}^{h} 〔 UF_{h,td} \times \frac{MAP_y}{(d_y \times 24)} 〕 \qquad \cdot\cdot\cdot\cdot(3.6)$$

3.1.6 The Portsmouth Bypass (Ohio)

For the Portsmouth Bypass, the hourly deduction amount is regulated in accordance with the type of facility. Table 3.6 shows the hourly deduction for 1-lane and 2-lane closures of the Mainline due to the duration of Unavailability. The hourly payment deduction ratio is calculated in the center column on the same table using MAP (=25.89 million $/year = 2,955 $/hour).

3.2 Comparison of Payment Adjustment Mechanisms on PPP Projects in the U.S.

In this section, the payment adjustment mechanisms for Unavailability on PPP projects are assessed and compared.

3.2.1 Comparison of Payment Adjustment by Category of Hours

According to the analysis of payment deduction ratios on each project in the previous section, the public sector sets the payment deduction at various levels according to priority hours. Figures 3.1 and 3.2 show the payment deduction ratios in 3 (three) categories, that is, high (peak)-, mid- and low-priority hours (shown for each project in Table3.7) in a day when one or all (2-4) lanes are closed.

Table3.7 supposed priority hours for each project

	High-	Middle-	Low-
I-595, I-4	6:00-9:00 16:00-19:00	9:00-16:00 19:00-22:00	22:00-6:00
I-69	6:00-9:00 16:00-19:00	-	9:00-16:00 19:00-22:00 22:00-6:00
East End	6:00-11:00 15:00-19:00	11:00-15:00 19:00-22:00	22:00-6:00
Presidio	7:00-11:00	6:00-7:00 11:00-21:00	21:00-6:00
Portsmouth	6:00-9:00 15:00-18:00	9:00-15:00 18:00-21:00 5:00-6:00	21:00-5:00

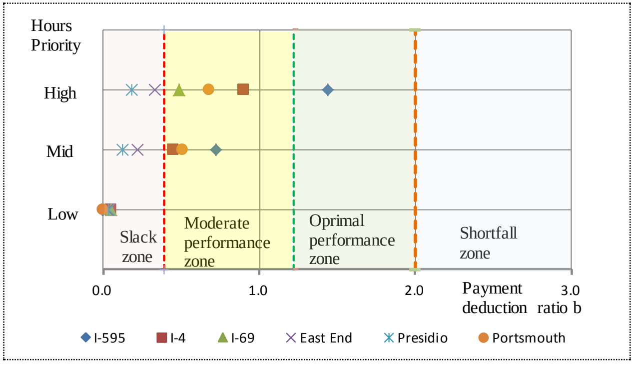

Fig. 3.1 payment deduction ratios for 1-lane closure on the six projects

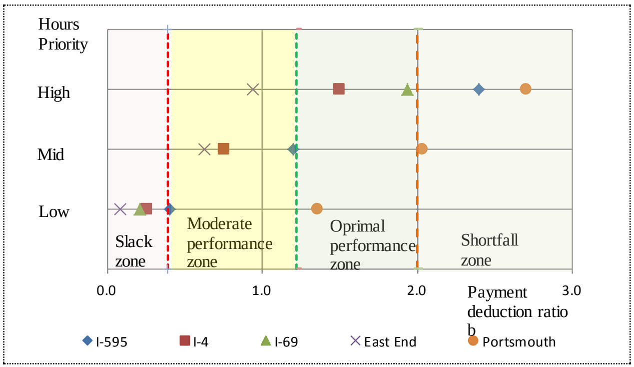

Fig. 3.2 payment deduction ratios for all-lanes closure on the six projects

In these figures, the 4 (four) zones (slack, moderate performance, optimal performance, and shortfall) and 3 (three) boundaries (incentive boundary at b=1.22; slack boundary at b=0.389 for a concessionaire with E=1.8; and participation boundary at b=2.0, where the risk limit for risk occurrence probability is set at 3%) are indicated.

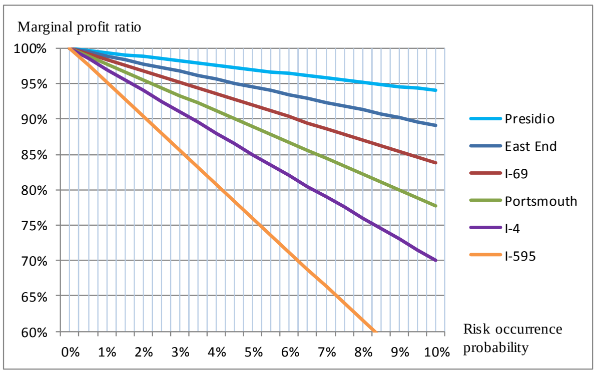

Fig. 3.3 marginal profit ratio of 1-lane closure on the six projects

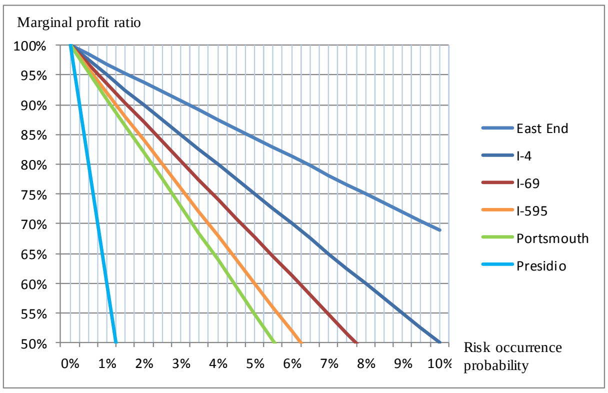

Fig. 3.4 marginal profit ratio of 3-lanes closure on the six projects

Some general trends and various characteristics of the highway projects can be interpreted from Figures 3.1 and 3.2, as well as Tables 3.1-3.6.

(1) Payment deduction ratios for all-lane closures on the Presidio (the value of the payment deduction for all-lane closures is too large to be indicated in Fig.3.2), a 2-lane closure for 12 hours (from 6:00-18:00) on Portsmouth, and 3-lane closures for 6 hours (from 6:00-9:00 and 16:00 – 19:00) on the I-595 are greater than the limited ratios of the participation boundary (b=2.0), which means they face relatively more severe conditions.

(2) Payment deduction ratios for a 1-lane closure and all-lane closures during low priority hours (around midnight) are low in the slack zone for every project except for the case of an all lane closure on Presidio and Portsmouth.

(3) The severity of payment deductions differ by the priority hours and the number of closed lanes, and may be attributed to the conditions of facilities, highway traffic, natural weather, and other factors that affect management strategy.

Next, as for the case of 1-lane closure and all-lanes closure on every project, the relation between risk occurrence probability and the concessionaire's marginal profit ratios is indicated in Fig.3.3 and Fig.3.4.

In the case of 1-lane closures (Fig.3.3), the condition of I-595 is the most severe. If the risk occurrence probability is more than 4.2%, a concessionaire's marginal profit ratio becomes less than 80%. Conversely, though risk occurrence probability becomes higher than 10% on I-69, East End or Presidio, a concessionaire's marginal profit ratio may be kept over 80%.

In the case of all (2-4) - lane closures (Fig. 3.4), if risk occurrence probability on the Presidio happens to be more than 0.5%, the concessionaire's marginal profit ratio becomes less than 80%. As for the other projects, if risk occurrence probability stays within 2.1% to 6.4%, the concessionaire's marginal profit ratio may be kept over 80%.

3.2.2 Concessionaire's Profit Considering Risk Occurrence Probability

In this section, the concessionaire's expected profit ratio on every project is compared in accordance with the assumption of lane-closure occurrence probabilities and the condition of payment deduction ratios examined above.

Here, the probabilities of lane-closures are set at assumed levels (see Table 3.8). Payment deduction ratios of each project are organized in Table 3.1 to 3.6, respectively. Hence, the hourly payment deduction amounts can be indicated as:

$$Q_1 = \Sigma(b_i \times n_i)/24 \times W_1 \quad \cdot\cdot\cdot\cdot(3.7)$$

Standard profit levels before the deduction can be indicated as the previously defined Eq. (2.12):

$$R = (1 - k_1) \times W_1 \qquad \cdots\cdot(2.12)$$

Here, initial expected profit without consideration of additional costs can be indicated using the ratio k_2 as follows:

$$R_1 = k_2 \times (1 - k_1) \times W_1 \qquad \cdot\ \cdot\ \cdot\ \cdot(3.8)$$

From equation $R - Q_1 = R_1$, we can obtain:

$$k_2 = 1 - \Sigma\,(b_i \times n_i) / 24 \cdot (1 - k_1) \qquad \cdots\cdot(3.9)$$

Here, if a concessionaire tries to keep the target profit ratio, the required ratio for MAP (W) is obtained from the previously defined Eq. (2.18):

$$W \geqq W_1 \times \{k_1 + k_2 \times (1 - k_1) + n \times b\} \qquad \cdots\cdot(2.18)$$

Using Eqs. (3.9) and (2.18), as well as Table 3.1 to 3.6 and 3.8, the concessionaire's initial expected profit ratio on each project for Unavailability and the required ratio for initial MAP to obtain maximum profit (a marginal profit rate of 100%, which is defined as k_2=1.0) are indicated in Table 3.9 and Fig. 3.5 (Typical cost ratios for initial income is assumed to be at a level of k_1=0.7). Here, the maximum level of profit refers to a concessionaire obtaining $0.3 \times W_1$ when k_2=1.0.

As described above, once risk (lane-closures) occurrence probability values are assumed, the concessionaire's initial expected profit ratio is forecasted and probability values can be used to assess the profitability of a project. If a concessionaire suffers losses using the initially estimated MAP, they can re-estimate the required ratio for MAP to obtain target profits.

According to assumptions of risk occurrence probability taken here, payment deduction ratios set forth on the Presidio may be in severe condition, resulting in initial expected profit ratios falling below 70%. The required ratio for initially estimated MAP which is needed for every project not to become lower than the marginal profit ratio of 100% is calculated in Table 3.9 and indicated in Fig. 3.5. If risk occurrence probability changes, the concessionaire's required ratio for MAP also changes according to the broken line in Fig. 3.5.

Table 3.8 assumption of risk occurrence probability

	Number of closed lanes				Total Probability
	1	2	3	4	
2 lane part	3%	1%	-	-	4%
3 lane part	3%	2%	1%	-	6%
4 lane part	3%	2.33%	1.67%	1%	8%

(*) Values above are applied to duration of day time and half of values are applied to duration of mid night(22:00 to 6:00)

Table 3.9 concessionaire's required profit ratio

Project	Lanes (Direction)	Σ $b_i \times n_i$	Average risk occurrence probability n(%)	Average payment deduction ratio(b)	Initialy expected profit ratio	Ratio for initial MAP
I-595	3 (One)	1.189	5.000	0.991	83.50%	105.0%
I-4	3 (One)	0.756	5.000	0.63	89.50%	103.2%
I-69	3 (One)	0.513	5.000	0.428	92.90%	102.1%
East End	4 (Both)	0.620	6.667	0.388	91.30%	102.6%
Presidio	3 (One)	2.246	4.889	1.914	68.80%	109.4%
Portsmouth	2 (One)	0.646	3.333	0.808	91.00%	102.7%

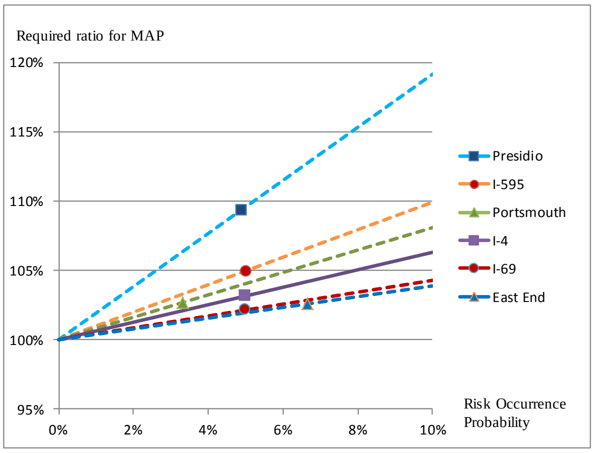

Fig. 3.5 risk occurrence probability and required ratio for MAP

4. Conclusions

In this paper, the authors focus on A/P systems which have been increasingly applied to highway PPP projects in the U.S. and analyzed the payment adjustment mechanism for Unavailability from the viewpoint of the principal-agent problem. As a result, some points can be clarified as follows,

(1) A payment adjustment mechanism for Unavailability is formulated, and by using the proposed formula, conditions of payment deduction ratios to maximize public sector

benefits without causing agency-slack by the concessionaire are examined.

(2) Simply setting optimal payment deduction ratios is insufficient for maximizing public sector benefits and lowering the possibility of agency -slack by the concessionaire. These values are highly dependent upon the efficiency (E) of private sector participants. Companies must retain technological and managerial capabilities to efficiently shorten Unavailability periods.

(3) Based on the proposed formula model, payment adjustment mechanisms applied to highway PPP projects in the U.S. are assessed and compared. As a result, it is clarified that the profitability of each project may differ in accordance with the degree or scale of payment deduction ratios.

Lastly, it is essential to gather data and materials concerning the characteristics of facilities and highway traffic as well as the risk occurrence probability for Unavailability at each road to regulate appropriate payment deduction ratios for each project.

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