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Price of Anarchy of The Airport Operator, Airline and Traveller Social Costs Using The Game Theory

Roslina Ahmad[1*], Harlina Suzana Jaafar[2]
[1] Malaysia Airports Holding Berhad, Persiaran Korporat KLIA, 64000, KLIA Sepang Selangor Malaysia. [2]Malaysia Institute of Transport, Universiti Teknologi MARA, 40450 Shah Alam, Selangor Malaysia
*Corresponding author: drroslina71@gmail.com

Abstract

This paper discusses the Price of Anarchy of the airport operator, airline, and traveller using Game theory of all players in the system due to the flight departure delay. These study could gauge the social cost incurred by airport operator, airline, and traveller due to operational glitch that delays the flight departure from its schedule for more than two hours in airport. In airport operation management, the delay may be due to rescheduling of departure time, technical faulty, inefficient airline staff, operational glitch, security reason, bad weather, and other reasons that could cause congestion in the terminal and airfield area. However, this study only focuses on the social cost incurred by the airport operator (player 1) and traveller (player 3) due to flight delay caused by airline (player 2). This problem could cause congestion in the terminal because the airport operator (player 1) needs to hold the traveller (player 3) for longer period of time and this depends on the rescheduled time of the next flight by the airline (player 2). Due to this incident, the airport operator (player 1) and traveller (player 3) have incurred higher social cost. This study uses the analytical tools that can evaluate the potential increase of the social cost as the sum of the players.

Keywords: Price of Anarchy, Game Theory, Social Cost, Airport Operator, Flight Delay

Introduction

Airport terminal congestion can be caused by several factors related to airport and airline operational glitches that charge social cost to other players. Many studies can be found on the airport congestions in the terminal, at the runway, parking apron, airfield and landside. A study by Wan, Jiang, and Ziang (2015) has identified two types of congestions; firstly, the congestion in the terminal related to passenger behaviour by adopting deterministic bottleneck model that is totally “atomistic”, and secondly, the congestion in the runway that is

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considered as an "internalization" that implicates the airlines and airport operators, evaluated using simple congestion model.

A study on the airport economic congestion pricing by Pels and Verhoef (2004) reveals the growing congestion levels currently experienced by many airports. The models used for this study is the combination of stochastic queuing theory using Vickrey-type bottleneck model. This study aims to provide the solution concept for congestions in the terminal building. Firstly, the airline market power has engaged in oligopolistic competition at different sub-markets. Secondly, part of external travel days imposed by the aircraft are internal to the operator and accounted in congestion toll. Thirdly, different airports with international network will not be typically regulated by the same authority. However, all these studies are related to airport management either on business or operations. In contrast, this study focuses on the congestion toll that has caused the traveller' extended travel days or traveller has incurred the social cost due to additional travel days.

1.1 The Price of Anarchy (PoA)

In Game theory, the Price of Anarchy (PoA) is an economic concept that measures how the efficiency of the system degrades due to selfish behaviour of the agents. In this study, the travel time valuation is the total time spent in the terminal that includes the check-in time (departure), landing time (arrival) perceived time (walking distance to contact pier), shopping time (personal spending while waiting for boarding), personal or waiting travel time (duration spending in terminal), and generalized costs and external cost (transit time). This study focuses on the social cost incurred by airport operator (***player 1***) when the traveller (***player 3***) uses the airport facilities for more than two (2) hours excluding the internal costs such as the air ticket fare, car fuel, toll, car park charge or taxi fare, and travelling time to the airport. Meanwhile, the airline (***player 2***) is an air transport service provider for

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the traveller that travel from one destination to another destination and also embark and disembark from the airports managed by the airport operator.

This paper intends to discuss the social cost incurred by the airport operator (***player 1***) and the traveller (***player 3***) due to the flight delay by airline (***player 2***). This is to quantify the performance of the system of selfish agents (airlines) as the ***player 2*** indirectly affects others in the system and incurs higher social cost such as for the airport operator (***player 1***) to hold the traveller longer in the terminal and for the traveller (***player 3***) to wait for another flight. At the same time, the traveller (***player 3***) has to also incur higher social cost due to idling waiting time, rescheduling the meeting or programme, accommodation, transportation, and many more. The airline (***player 2***) could reduce other players' social cost if it takes immediate action by changing the flight schedule within one (1) hour in order to minimize the social cost of those players (***player 1 and player 3***). As such, the analytical tools developed by Dutting (2015) could allow to (upper and lower) bound the potential increase of the social cost. Thus, the social cost is defined as the sum of all players' cost; the ***s*** let cost (***s***) = ∑ i∈ *N* ci(***s***) and ***s*** is the social cost with the consideration of *'maximum cost'* possibly incurred by the airport operator and traveller.

1.2 The Social Cost of Traveller (Passenger of Airline)

The social cost in this study refers to the travel time valuation that is the travel time in terminal, clock time (check in and departure), perceived time (walking distance to contact pier), paid (personal spending while waiting for boarding), personal travel time (duration spending in terminal), generalized costs, and effective speed. This study focuses on the passenger' or traveller' time while using the airport facilities provided by the airport operator excluding the internal cost of the air ticket fare, car fuel, toll, car park charge, taxi fare, and travelling time to the airport. To understand the Price of Anarchy of the traveller, this study

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uses the terminal facilities such as the check-in counter, passport clearance, security clearance, waiting time at departure lounge, and boarding time.

Based on Dutting (2015), the PoA is defined as follows : Let be a set Eq be a set of probability distributions over the set of states *S*, for some probability distribution P, let cost *(p)* = $\sum$ s∈*S* p(*s*) cost (*s*) be expected social cost. The Price of Anarchy (PoA) for Eq is defined as:

$$PoAEq = \frac{\max_{p \in Eq} cost(p)}{\min_{s \in S} cost(s)}$$

**This study focuses on the Passenger Security Service Charge (PSSC) at KL International Airport Main Terminal Building and these charges are carried out pursuant to Regulation 170A of the Civil Aviation (Amendment) Regulations 2006. It is stated that a security charge shall be payable in respect of any person boarding an aircraft carrying passengers for hire or reward at rates as follows :*

- *All stated PSCs are inclusive of Passenger Security Service Charge (PSSC) components at RM6 (international) and RM3 (domestic). It will be collected together as part of the cost of ticket, similar to the current passenger service charge collection procedure.*

The Passenger Service Charge (inclusive of PSSC*) in KL International Airport can be seen in the following Table 1-1

Table 1
Revised PSC of Malaysia Airports

	Revised PSC, effective 1 January 2017 (RM)		
	Domestic	ASEAN	International (Excluding ASEAN)
KLIA	11	35	73

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In this study the PSSC will be used based on the international PSSC charge for KLIA as the airport cater for Full Fare Service Airlines and the type of aircrafts that embark and disembark from this airport is a wide body size of passenger aircraft such as A380, Boeing 787 Dreamliner, Dash * Q400 and other types of wide body aircrafts. Thus, the suitable cost of this terminal PSSC is RM73 for each traveller or passenger to depart from this airport within two (2) hours of the terminal facilities use upon arrival to the main terminal building,

Based on the given PoA formula above, the cost of per passenger for every minute will be;

$$\frac{\text{RM73}}{\text{120 minutes}} = \text{0.608cent/minute social cost}$$

Thus, the PoA of every flight delay on the traveller social cost for every minute in the terminal building is an additional cost to the airport operator. We assume that the acceptable delay of aircraft to depart is around 30 minutes and the traveller’s minimum social cost shall start at RM18.20. While the maximum delay to depart is around 60 minutes. Indirectly the social cost could increase to RM36.50 for ***player 1*** and ***player 3,*** thus, the total PoA for both players is -RM73.

1.3 The Social Cost of Airport Operator

To illustrate the calculation of the PoA, the following motivating example is given;

The departure delay of aircraft due to minor technical problem requires extra one (1) hour or 60 minutes additional time to check the aircraft system. Thus, the flight delay to disembark from airport as per flight scheduled will incur social cost to the the airport operator and traveller as the following:

Consider the minimum acceptable delay by the airport operator and traveller is around 30 minutes and the social cost for every player:

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$$\text{PoAEq} = \frac{\underline{max\ p \in \text{Eq}\ \text{cost}\ (73)\ < f(x)}}{min\ s \in S\ \text{cost}\ (30) < f(s)}$$

0.608 x 30minutes = RM18.20 x 2 (passenger + operator) (excluding others) if the delay is more than 30 minutes the cost of PoA as in Table 1-2;

Table 2
Summary of the Price of Anarchy of Airport Operator and Traveller

	Schedule Flight	**PSC RM**	**Delay**	**PoA**
Traveller (p3)	On time	73.00	60 minutes	-RM36.50
Airlines (p2)	On time boarding	-	60 minutes	Parking charges
Airport Operator (p1)	On time clearance	-	60 minutes	-RM36.50
PoA social costs values				-RM73.00

Flight delay of the airline (***player 2***) due to any operation matters will affect other players and also incur social cost to the airport operator (***player 1***) in the use of terminal facilities and space (departure lounge, toilets and rest area) as well the facilities for check-in, immigration, and security check. At the same time, the traveller (***player 3***) needs to wait longer for the rescheduling of the flight or to check out from the airport or to check-in again for another flight. Thus, the social cost incurred by the airport operator ***if*** delay is within two (2) hours is –RM73.00. Besides that, the passenger incurs the social cost indirectly in case of idling time, loss of opportunity, spending time in the terminal, cancelation cost such as hotel, rescheduling of travel programme, and airport transit cost if any .

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All hidden cost due to the delay of aircraft of ***player 2*** for more than one (1) hour has caused an increase on the social cost to ***player 1*** and ***player 3***. However, the social cost caused by delay on departure of aircraft due to unfavourable weather, emergency matters, security tightening and others related to external issues on safety reason will be bared by all players. This external cost normally was not discussed as this is part of the airport responsibility and obligation for compliance to the safety international standard (International Civil Aviation Organization) for air transport traveller. Anyhow, if the delay is due to airport operator faults, thus the external cost should be calculated by the airport operator.

The overall social costs shall include the internal cost and external cost, as we assume that the traveller social cost will be at 0.608 cent per minute. Based on Villemeur, Ivaldi, Quinet and Urdanoz (2014) the social cost for air traffic delay will be measured from the minimum travel time between the realized and the scheduled arrival time. It is also strategically controlled by the scheduler with inclusion of buffer on the arrival schedule of aircraft to embark in the airport. Meanwhile, the airport operator (***player 2***) only prepares the aircraft parking bay as per scheduled and for any delay the cost of parking apron is imposed accordingly. However, this study will not focus on the social cost incurred by the airport alone. The delay of departing aircraft due to rescheduling, buffing time, and any operational or technical glitch is included within two (2) hours of the traveller and airport operator social cost.

Based on the calculation with the above method, the social cost can be summarized in the Game matrix Prisoner's Dilemma in Table 1-3 below ;

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Table 3
Game Matrix of social cost

<table>
<tr><td colspan="2" rowspan="2">Prisoner's Dilemma with payoff</td><td colspan="2">player 2</td></tr>
<tr><td>On time (OT)</td><td>Delay (D)</td></tr>
<tr><td rowspan="2">player 1 and player 3</td><td>On time (OT)</td><td>(0,0,0)</td><td>(-73,-73,0)</td></tr>
<tr><td>Delay (D)</td><td>(-73,-73,0)</td><td>(-73,-73, -73)</td></tr>
</table>

The **prisoner's dilemma** is an example of a game analysis in which the players in the system might not cooperate or even it appears they will act to their best interests for their own benefit. This game can be used as a model involving cooperative behaviour of multiplayers in the system. Normally, the use of this model can also be applied to situations not strictly matching the formal criteria of the classic or iterative games. This model analyses the players strategic action in the system that could gain important benefits from cooperating or suffer due to the failure of any players in the system. The scenario of this case is shown in the game matrix below;

*When, **player 2** departs on-time (OT) both **player 1** and **player 3** are equilibrium (Eq). If **player 1** is (OT) but **player 2** is (D) for 2 hours, thus **player 1'** social cost incurs (-73), so does **player 3** (-73). If both **player 1** and **player 2** are (D) for 2 hours, the social cost will be bared by all players (-73, -73, -73) in the system.*

Thus, based on the above set game in Table 1-3, when all players are cooperative without any flight delay (***player 2***), the payoff is 73 for two hours (120 minutes) for the use of the airport facilities (***player 1***) and the traveller departs on

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time (***player 3***). Thus, all players benefit from being cooperative or equilibrium (**Eq).** But if the flight delays within two hours (120 minutes), the social cost is incurred by the players (***player 1*** is -73 and ***players 3*** is also -73). If ***player 1*** and ***player 2*** delay due to operational matters, thus all players will indirectly incur the social cost of (-73,-73,-73).

In any cases, if the airline operator (***player 2***) has flight delay for more than one hour up to 24 hours due to the operational reason the PoA for the traveller (***player 3***) and airport operator (***player 1***) will increase accordingly. The delay will also cause congestion in the terminal and indirectly will reduce the comfort and service level in the terminal building. This situation will cost the airport operator (***player 1***) because of holding the traveller (***player 3***) longer in the terminal building.

As has been explained above, the incurred cost of the ***player 1*** and ***player 3*** is not as per departure schedule due to various reasons and the PoA is incurred by all players in the system. Another cost affected the airport operator (***player 1***) is the congestion in the terminal during pick hours which includes in the unforeseen social costs such as reducing the comfort level and efficiency of the system, longer queuing time, space constraint, higher frequency of airport facilities use, and other related systems in the terminal building.

However, it seems that the airport operator (***player 1***) covers the cost through the traveller (***player 3***) spending or shopping in the terminal for buying food or goods while waiting for the next flight. In fact, the issue of flight delay has caused congestion in the airport mainly during the pick hours which becomes a problem to airport operator (***player 1***). This delay indirectly affects other airport operational systems such as the changing of aircraft parking bay and slot, the occupancy of the departure lounge, and the baggage handling services, besides holding the traveller (***player 3***) longer in the terminal and on the air. All the social cost incurred by the airport operator (***player 1***) due to flight delay by airlines (***player 2***) was never discussed in depth among the airport operators.

Conclusion

This study focuses on the flight delay of airline (***player 3***) that has caused congestion in terminal. Normally, the congestion in the terminal caused by the airport operator (***player 1***) or related government agencies during pick hours is related to check-in, immigration clearance, inefficient baggage ground handler, technical problem related to Mechanical and Electrical or Information Technology services, all of which should delay a flight for one or two hours at the longest.

If the delay caused by the airline (***player 2***) due to aircraft technical glitch or operational issue takes more than two (2) hours up to twenty four (24) hours, the PoA score of the traveller (***player 3***) indirectly increases due to the connecting activities or transfer time, a change from the original travel plan with cancellation of accommodation, transportation, travel agencies and many more. Meanwhile, holding the traveller (***player 3***) within that period will be a cost to the airport operator, unless the airline (***player 2***) provides its own rest area (delay facility). Analyzing the cost of the players' PoA is a study to understand the cost incurred by all parties in airport using the Game theory. The preliminary study of airport congestion can be explored more by using the Congestion Game, a subclass of Game theory introduced by Rosenthal in 1973.

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