wctr'04
4-8 july 2004 / istanbul-turkey

AN INVESTIGATION OF OPERATIONAL UNCERTAINTIES IN AIRLINE SCHEDULES AND THE IMPLICATION ON SCHEDULE DESIGN AND RELIABILITY

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Abstract

The operation of aircraft turnaround services has become the focal point when airlines try to control delays and expect the design of extra schedule buffer time for aircraft turnaround to absorb delays in aircraft rotation. The growing complex nature of airline schedule design and the growing pressure on aircraft utilisation also make the task of schedule punctuality control more difficult than ever. Hence, the objective of this paper is to investigate operational uncertainties in aircraft turnaround operations and the effects of these uncertainties on schedule punctuality control issues. Two empirical analyses are carried out and we find that airlines face different uncertainty issues at different airports. Some uncertainties come from schedule planning strategies, e.g. short aircraft turnaround time, and some are due to operation disruptions at airports such as passenger processing problems. From punctuality curve analyses, we find that flight punctuality is variant depending on the time of a day, operational efficiency of ground crew and more significantly depending on the design nature of flight schedules. Simulation models are applied to carry out scenario analyses for schedule planning purposes. Results show that by increasing 4% schedule time on an example route, flight punctuality could be improved by 14%. This example further reveals some thoughts about how flight punctuality and the overall schedule reliability could be managed by considering stochastic factors in schedule design.

Keywords: Operational uncertainties; Schedule punctuality; Schedule reliability
Topic Area: A3 Airports and Aviation

1. Introduction

The operation and control of airline schedule systems has nowadays become a highly complex task for airlines due to airline commercial requirements, growing airspace congestion and airport capacity constraints. Moreover, unexpected schedule disruption events make the adherence of airline schedule operations even more difficult to achieve. Due to the complex nature of airline operations, airline schedule systems have been nowadays recognised as Complex Adaptive Systems (CAS) and the induced operational problems as Complex System Operations Control (CSOC) problems (Campbell et al, 2001).

Tangible consequences of being lack of operational reliability in airline schedules are flight delays and increasing operating costs due to delays. Meanwhile, the intangible losses also come from passengers' ill will and time value losses. Eurocontrol, the responsible organisation of air traffic management in Europe, reported that the average aircraft movement delay in 2001 was 14 minutes and 25% of all air traffic movements were delayed by more than 15 minutes (Eurocontrol, 2001). If delays are transformed into monetary scales, it is estimated that a top-10 European carrier bears $100 to $400 million of delay costs annually which significantly degrade the profitability of airline business as well as its business competitiveness (Booz-Allen & Hamilton, 2001; Suzuki, 2000). Similar delay levels were also found in the National Air Space (NAS) of the US, where 27% of flights were delayed in 2001. Qantas, the Australian carrier, estimates that 1% improvement of schedule punctuality will bring Qantas additional $15 million profits in a year.

A more detailed investigation of delay causes by Eurocontrol revealed that 42% of delay causes were due to airline operational activities instead of the commonly blamed scapegoat—airspace capacity, which contributed 35% of delay causes in the same period of time, while the rest 23% of delays were due to other causes (Eurocontrol, 2001). Schedule delays are usually caused by stochastic disruption events and are gradually accumulated in the operation of airline schedules, if not absorbed by buffer times. Delays eventually transform into knock-on delays (or called 'reactionary delays'), which also partially result from airline schedule planning and poor ground operational capability to manage delays. An internal study by Austrian Airlines in 1999 revealed that 54% of its total delay costs were solely caused by knock-on delays, which severely impacted schedule reliability, business profitability and passengers' good will (Airline Business, 1999).

2. Current practices and observation

In the airline industry, some actions have been deployed to tackle the delay problem. Southwest Airlines in the US was forced to design more schedule buffer time at the price of reducing aircraft utilisation in order to maintain its schedule punctuality targets as well as its punctuality perception to passengers (Air Transport World, 2000). Some airlines opt to ground aircraft as backup fleet so as to respond to schedule disruptions with a more flexible manner. It has been realised both in the industry and academia that different scheduling strategies lead to different inherent levels of schedule punctuality (Airline Business, 1999; Wu, Caves, 2002). In a previous study by Wu and Caves (2002), it was found that in some cases, the low level of schedule adherence is mainly caused by airline schedule planning and poor efficiency of aircraft ground operations. With a minor 5% change of block time allocation in an aircraft rotation schedule, it was found in a schedule simulation that the overall punctuality level could be significantly improved.

In the literature, Trietsch (1993) investigated the influence of stochastic schedule punctuality on the optimisation of hubbing flight schedules. In Trietsch's model, the arrival and departure times of individual flights inbound and outbound a hub airport were described as independent stochastic variables and hence the overall system performance was optimised by minimising costs due to stochastic delays. This model considered aggregately the stochastic features of flight times on punctuality without further considering effects of stochastic factors within aircraft turnaround operations and aircraft rotations. A recent investigation by Wu and Caves (2002) focused on the influence of stochastic factors in aircraft rotations on current scheduling methodologies and proposed for the first time a framework to quantitatively evaluate the operational reliability of airline schedule systems. It was found by Wu and Caves that the reliability of airline schedules, in terms of schedule delay figures, could be significantly improved and optimised if schedule buffer times were designed to consider inherent stochastic factors in aircraft rotations. Mederer and Frank (2002) approached the airline schedule punctuality control issue by dealing with stochastic variables involved in airline operations and therefore suggested that certain schedule planning parameters (such as aircraft ground time) should be modelled as stochastic variables instead of deterministic ones.

Although some work has been done in the literature regarding the modelling of the aggregate stochastic effects of airline schedules, it is still not clear how stochastic variables such as airline operational activities influence punctuality and how an airline can response to this issue. Therefore, the objective of this paper is to investigate the causes of operational disruptions in airline operations and the implication on schedule design issues. This paper starts by presenting some empirical analysis results in Section Three. Key findings in Section Three form the base of a simulation model developed to simulate airline schedule operations. Case studies are given in Section Four to demonstrate the application of the simulation model by using historical data of a European airline. Further discussions are carried out in Section Five and conclusions given in Section Six.

3. Empirical analyses

Airlines usually monitor schedule delays and record delay causes by a specific coding system. The delay coding system developed by International Air Transport Association (IATA) is the most widely used coding system in the airline industry to record delays (IATA, 2003). Some airlines also develop supportive delay coding systems to supplement the IATA coding system according to specific needs. In the IATA coding system, delay causes are categorized into 100 types (No. 00- No. 99) and grouped into 12 major categories such as ‘cargo and mail’, ‘aircraft and ramp handling’, ‘passenger and baggage’, ‘weather’ and ‘reactionary’. Punctuality data from a European airline (Airline P, based at Airport AAA) is used in this paper for case study purposes. Due to information confidentiality, airline and airport identities are replaced by chosen codes.

3.1. Aircraft turnaround operations

Activities carried out in aircraft turnaround operation are illustrated by Figure 1 (Ashford et al, 1997). Activities can be categorised into two major work flows: (1) crew & passenger processing and (2) cargo & baggage processing. For instance, the work flow of crew & passenger processing starts from disembarking passengers, disembarking crew, cabin cleaning duties, boarding crew, crew check and boarding passengers. Disruptions to this work flow may come from lengthy disembarking passengers, late crew boarding, late passenger boarding and missing check-in passengers. Major delay causes to this work flow are shown in Table 1 and major causes to delay cargo & baggage processing flow are given in Table 2.

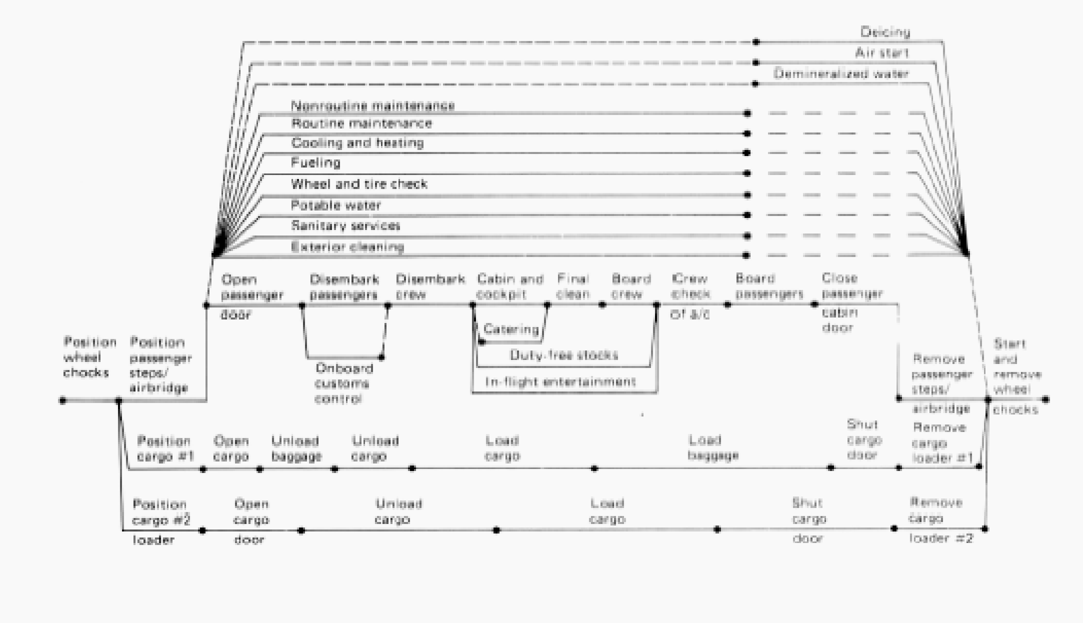


Figure 1. Operational flows of aircraft turnaround ground handling (Sources: Ashford *et al*, 1997)

Table 1. Crew & passenger processing

Activity Description	IATA Delay Codes & Description
Crew Boarding	**63, 94, 95** Late crew boarding, awaiting crew
Passenger Boarding	**11, 12, 14** Late acceptance, late check-in
Missing Passengers	**15** Missing check-in passengers
Flight Operations	**61, 62** Flight plan, operational requirements
Departure Process	**63, 89** Airport facilities, ground movement
Weather	**71, 72** Weather restriction at O/D airports, Removal of snow/ice/sand

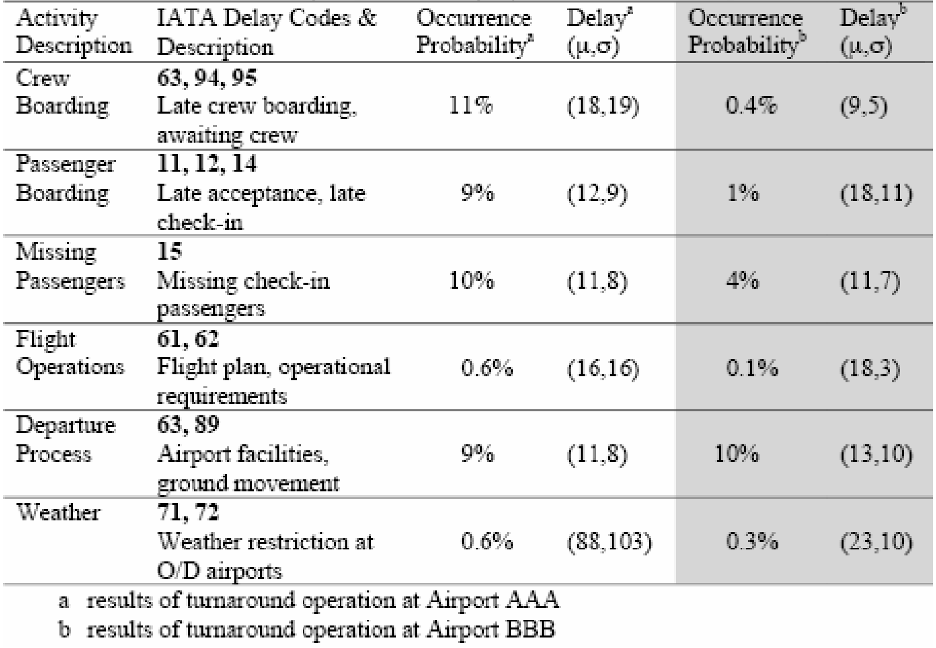
Table 2. Cargo & baggage processing

Activity Description	IATA Delay Codes & Description
Cargo & Baggage Unloading	**22, 23, 26** Late positioning & preparation
Aircraft Ramp Handling	**32, 33** Lack of loading staff, cabin load Lack of equipment, staff/operators
Cargo & Baggage Loading	**22, 23, 26** Late positioning & preparation
Passenger & Baggage	**11, 12, 18** Late check-in passenger, check-in counter congestion, late baggage processing

Punctuality data from Airline P is coded in IATA delay codes. Frequency analyses are conducted to examine the occurrence probability of disruption events and consequent delays. Two sets of data (Airport AAA and BBB) are used in the analyses and results are given in Table 3 and Table 4 below. Frequency analyses of turnaround operation at Airport AAA show that there is a high probability (11%) to encounter crewing problems. According to field observation and interviews with Airline P's staff, the high possibility of crewing problems is mainly due to the integration issue between crewing plans and aircraft rotation plans. Since Airport AAA is the base airport of Airline P, delayed aircraft rotation sometimes results in delayed crew for the other flights. It is found that Airline P encounters passenger boarding problems with an average probability of 9% at AAA and more significantly 10% chance to have check-in passengers missing in the airport. Delays due to 'departure process' also occur with 9% probability.

When this result is compared with results of turnaround operation at Airport BBB, it is found that 'departure process' also causes the highest delay probability, 10%, and there is also a probability of 4% to have passenger missing after check-in. Airport BBB is a major airport in Europe, so delays due to 'departure process' are more likely to occur because of busy airport ground operations and airport capacity restrictions. Since Airport AAA is a secondary airport in Europe, aircraft turnaround operations should not have such a high exposure to encounter delays due to 'departure process'.

Table 3. Crew & passenger processing by Airline P at Airport AAA, BBB

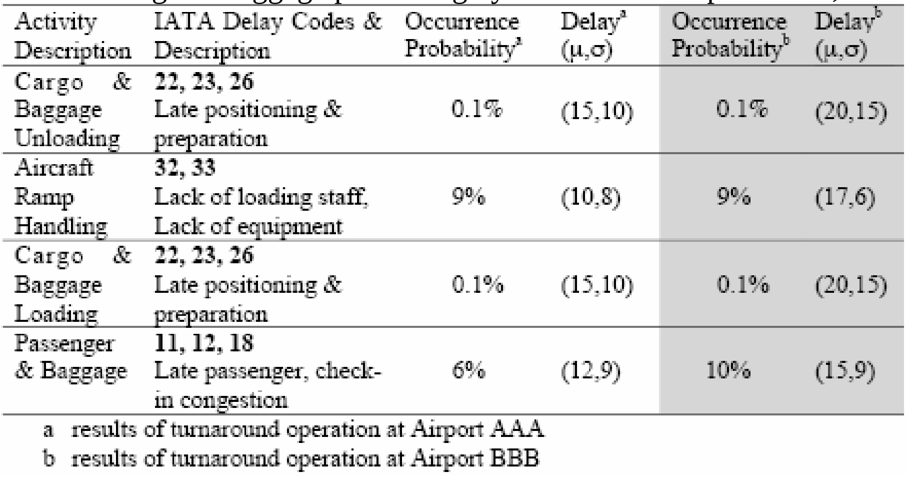


Activity Description	IATA Delay Codes & Description	Occurrence Probability[a]	Delay[a] (μ,σ)	Occurrence Probability[b]	Delay[b] (μ,σ)
Crew Boarding	**63, 94, 95** Late crew boarding, awaiting crew	11%	(18,19)	0.4%	(9,5)
Passenger Boarding	**11, 12, 14** Late acceptance, late check-in	9%	(12,9)	1%	(18,11)
Missing Passengers	**15** Missing check-in passengers	10%	(11,8)	4%	(11,7)
Flight Operations	**61, 62** Flight plan, operational requirements	0.6%	(16,16)	0.1%	(18,3)
Departure Process	**63, 89** Airport facilities, ground movement	9%	(11,8)	10%	(13,10)
Weather	**71, 72** Weather restriction at O/D airports	0.6%	(88,103)	0.3%	(23,10)

a results of turnaround operation at Airport AAA
b results of turnaround operation at Airport BBB

Regarding cargo & baggage processing, it is found in Table 4 that frequency results of turnaround operation at AAA and BBB are quite close to each other except in the category of 'passenger & baggage'. The higher occurrence of 'passenger & baggage' problem at BBB is because BBB is a busy airport with much workload on baggage handling than AAA. As a consequence, delays due to cargo & baggage handling problems are also higher than delays at AAA.

Table 4. Cargo & baggage processing by Airline P at Airport AAA, BBB



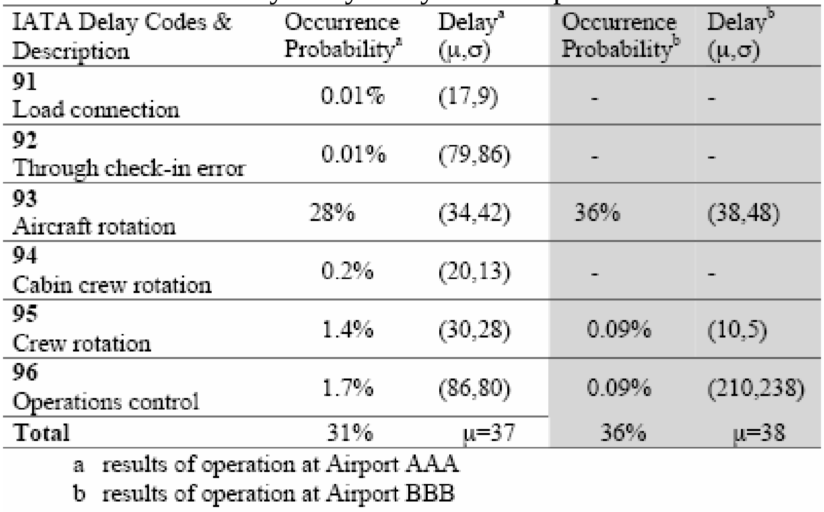
Activity Description	IATA Delay Codes & Description	Occurrence Probability[a]	Delay[a] (μ,σ)	Occurrence Probability[b]	Delay[b] (μ,σ)
Cargo & Baggage Unloading	**22, 23, 26** Late positioning & preparation	0.1%	(15,10)	0.1%	(20,15)
Aircraft Ramp Handling	**32, 33** Lack of loading staff, Lack of equipment	9%	(10,8)	9%	(17,6)
Cargo & Baggage Loading	**22, 23, 26** Late positioning & preparation	0.1%	(15,10)	0.1%	(20,15)
Passenger & Baggage	**11, 12, 18** Late passenger, check-in congestion	6%	(12,9)	10%	(15,9)

a results of turnaround operation at Airport AAA
b results of turnaround operation at Airport BBB

3.2. Delay propagation in aircraft rotations

From previous analyses, we have found that individual disruption events cause delays to aircraft turnaround services and hence departure delays. Schedule buffer time is usually designed in flight schedules to absorb stochastic delays to a certain degree depending on the airline's scheduling policy. If we do a further analysis to delays caused by 'Reactionary' factors, in Table 5 we find that these causes contribute about 30%-35% among all delay causes and the resulting average delay is about 37 minutes. Among factors in the 'reactionary delay' category, delays due to aircraft rotation (code 93) contribute over 80% of reactionary delays. This figure suggests that aircraft rotation schedule of Airline P is too tightly scheduled and needs to include some more buffer time in order to improve schedule reliability.

Table 5. Reactionary delay analyses at Airport AAA and BBB



IATA Delay Codes & Description	Occurrence Probability[a]	Delay[a] (μ,σ)	Occurrence Probability[b]	Delay[b] (μ,σ)
91 Load connection	0.01%	(17,9)	-	-
92 Through check-in error	0.01%	(79,86)	-	-
93 Aircraft rotation	28%	(34,42)	36%	(38,48)
94 Cabin crew rotation	0.2%	(20,13)	-	-
95 Crew rotation	1.4%	(30,28)	0.09%	(10,5)
96 Operations control	1.7%	(86,80)	0.09%	(210,238)
Total	31%	μ=37	36%	μ=38

a results of operation at Airport AAA
b results of operation at Airport BBB

After this frequency analysis, some conclusive remarks are made. First of all, the issue of passenger processing control is causing Airline P massive losses due to consequent delays. Airline P provides high frequency services between AAA and BBB, so passengers tend to show up at check-in counter at the last minute. Late check-in passengers usually cause baggage processing delays and passenger boarding delays. Field observation at AAA also validates this conclusion. Secondly, the aircraft rotation plan of Airline P needs to be fine-tuned to improve reliability. According to frequency analyses, delays due to crewing problems at AAA are quite significant (9%). Further frequency analyses of delays due to 'reactionary issues', e.g. aircraft rotation and crew rotation, show that a high occurrence probability of 31% is due to reactionary delays. This is a result of tight aircraft rotation plans by which low-cost airlines use to increase aircraft utilisation and profitability. It is minded that such a tight schedule is in-fact a double-edged sword, which brings profitability and also high operating losses due to delays and schedule changes. This is also the major reason why Southwest Airlines are forced to increase schedule buffer time to relax aircraft rotation schedules at the price of reducing aircraft utilisation. Thirdly, when the load factor of some flights goes up, the chance to have passenger and baggage handling delays also increases significantly. If this issue is not carefully considered in schedule planning, delays are likely to occur to certain flights and may drag down the reliability of the whole schedule.

3.3. Punctuality control issues -- AAA-BBB route by airline P

Although delay code analyses reveal some clues about why a flight is delayed, there is more information required to complete the puzzle of schedule punctuality control. Regarding punctuality control, airlines need to know the statistical characteristics of individual flight operations at different airports, at different times and how stochastic factors affect airline operations. The same set of data form Airline P is analysed to provide some insights for punctuality control and schedule planning strategies.

Punctuality data of the city pair route, AAA and BBB, by Airline P is used to draw arrival/departure CDF (cumulative density function) curves and PDF (probability density function) curves. Departure and arrival punctuality curves outbound AAA to BBB are shown in Figure 2 & 3 and the summary delay figures are given in Table 6. It is found that the departure punctuality (denoted by ‘DZero’) at AAA is only 23%, while the punctuality within 15-minute delay (denoted by ‘D15’) increases to 69%. On the arrival bound into BBB, we find that the arrival traffic has an average 56% of DZero punctuality and 77% of D15 punctuality. It implies that the buffer time for AAA-BBB route is mainly designed in the airborne block time in order to recover ground delays and possible airborne delays. This scheduling policy also improves the arrival punctuality at the destination airport, even though the departure punctuality at the origin airport might be low.

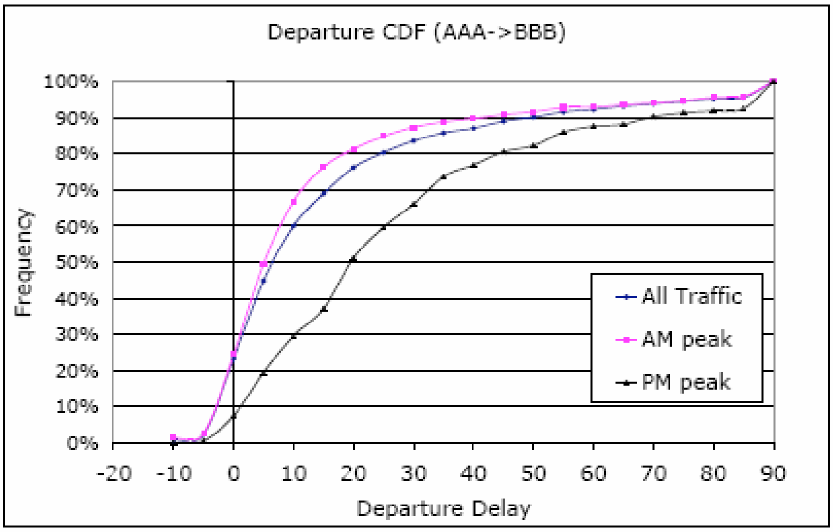


Figure 2 Departure CDF outbound AAA to BBB by Airline P

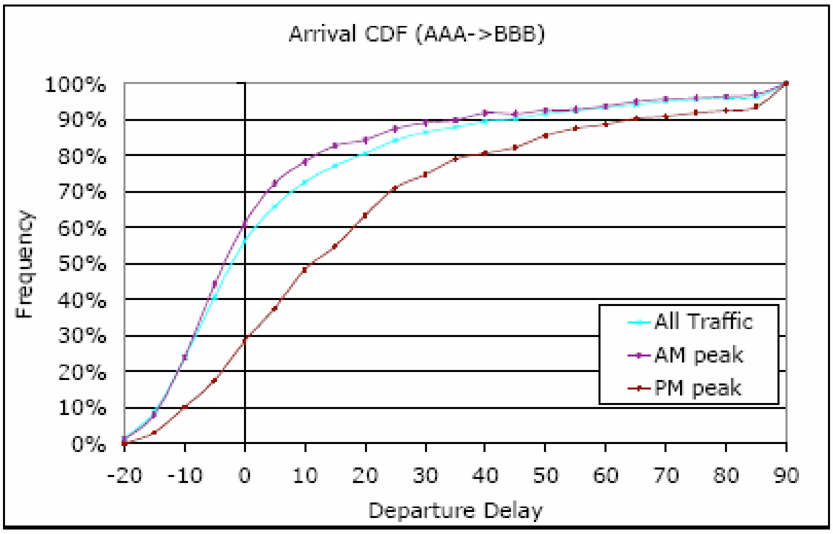


Figure 3 Arrival CDF inbound BBB from AAA by Airline P

Table 6. Mean delays on AAA-BBB route operated by Airline P

	All traffic	Morning flights (< 10.00 hrs)	Evening flights (> 17.30 hrs)
Departure Delay (outbound AAA)	20 mins	18 mins	32 mins
Arrival Delay (inbound BBB)	15 mins	14 mins	25 mins
Arrival Delay (incl. early arrivals)	11 mins	9 mins	23 mins

When the punctuality data of flights in morning peak hours (earlier than 10 am) are extracted from the data set to compare with flights during evening peak hours (later than 5.30 pm), it is surprising to find in Figure 2 and Figure 3 how significantly evening flights are influenced by reactionary delays accumulated from earlier flight operations on AAA-BBB route. It is found that the departure punctuality of morning flights outbound AAA is not well controlled. Accordingly, delays in the early rotation segments propagate into later flights. This observation is supported by delay figures given in Table 6. The average departure delay for morning flights is 18 minutes and the average departure delay for evening flights rises to 32 minutes. After a further discussion with Airline P, it is validated that the AAA-BBB rotation schedule is too tightly designed to absorb delays. When the CDF curves of outbound BBB-AAA flight are drawn in Figure 4 for comparison purposes, we find that the outbound BBB punctuality is better controlled, but the overall schedule punctuality on BBB-AAA route is dominantly influenced by aircraft turnaround operations on the AAA side. When the PDF curves of outbound AAA and outbound BBB flights are compared in Figure 5, it clearly shows different operational results due to schedule planning and ground operation disruptions.

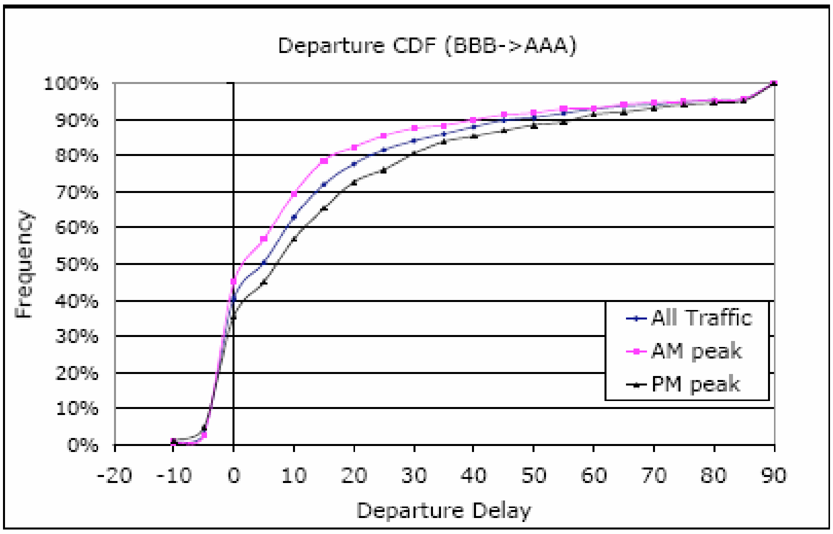


Figure 4 Departure CDF outbound BBB to AAA by Airline P

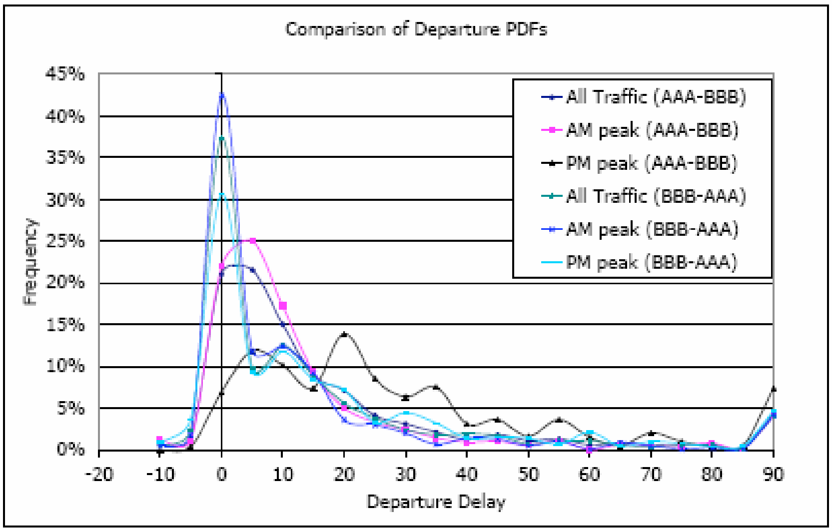


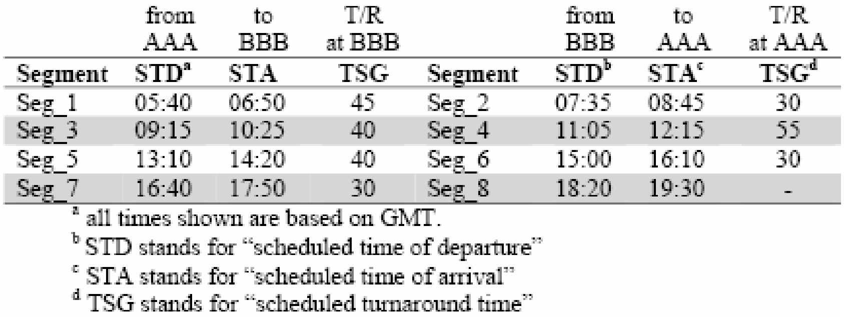
Figure 5 Departure PDF comparison between outbound AAA and outbound BBB by Airline P

4. Simulation approach

4.1. Aircraft rotation simulation

The rotation schedule of an aircraft (B737) between AAA and BBB by Airline P is chosen to be the simulation example. This aircraft was scheduled to depart AAA at 05.40 hours and continued shuttle services between two airports until 19.30 hours arriving at AAA as shown in Table 7. The scheduled turnaround time (denoted by TSG in Table 7) varied from 30 minutes to 55 minutes. The scheduled standard turnaround time for a B737 by Airline P was 30 minutes at AAA and 40 minutes at BBB. A detail description of the aircraft rotation simulation model (ARS model) used in this scenario analysis can be found in a paper by the author (Wu, Caves, 2002).

Table 7. Aircraft rotation schedule on the AAA-BBB route by Airline P



	from AAA	to BBB	T/R at BBB		from BBB	to AAA	T/R at AAA
Segment	STD[a]	STA	TSG	Segment	STD[b]	STA[c]	TSG[d]
Seg_1	05:40	06:50	45	Seg_2	07:35	08:45	30
Seg_3	09:15	10:25	40	Seg_4	11:05	12:15	55
Seg_5	13:10	14:20	40	Seg_6	15:00	16:10	30
Seg_7	16:40	17:50	30	Seg_8	18:20	19:30	-

[a] all times shown are based on GMT.

[b] STD stands for "scheduled time of departure"

[c] STA stands for "scheduled time of arrival"

[d] TSG stands for "scheduled turnaround time"

The ARS model was calibrated by using historical schedule and punctuality data from Airline P. The rotation schedule is simulated 1,000 times by the ARS model to reduce potential simulation noises. When simulation results are compared with observation results in Figure 6 and Figure 7, it is found that the simulation of ARS model matches observation data quite closely, though minor differences still exist. In Figure 6, we find that the mean departure delay increases from 9 minutes for Seg_1 to 13 minutes for Seg_4. Airline P assigned a long turnaround time (55 minutes) for Seg_5 at its base airport AAA, so the departure delay for Seg_5 is better controlled with only 8 minutes delay. However, both departure and arrival delays increase after Seg_6 due to short aircraft turnaround time (30 minutes) allocated in the schedule.

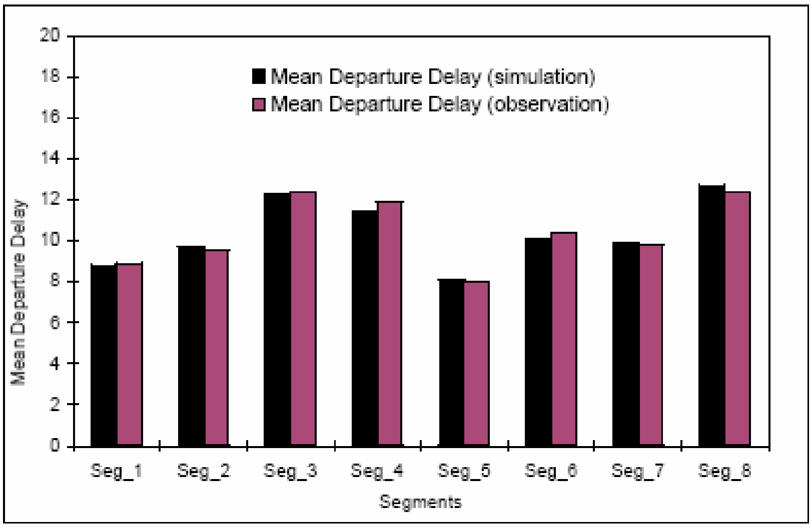


Figure 6. Results of simulation and observation (Departure delays)

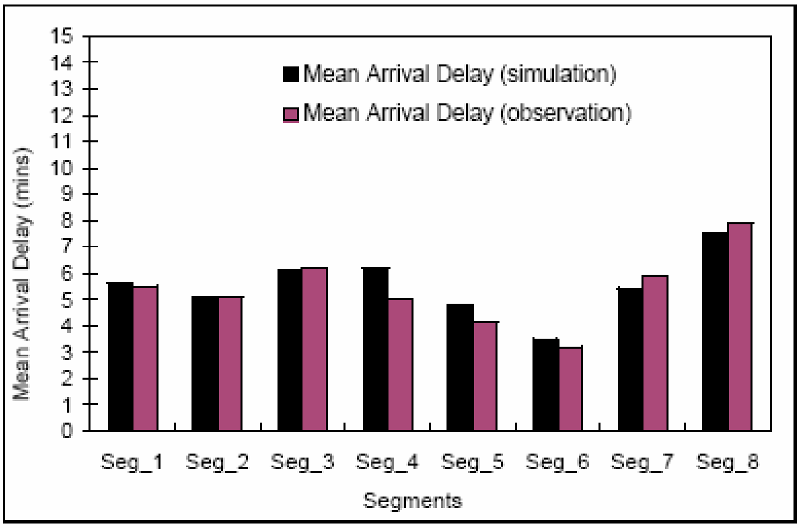


Figure 7. Results of simulation and observation (Arrival delays)

4.2. Priority scheduling

It is clear to see in Figure 6 and Figure 7 that flights are subject to variant levels of delay depending on flight schedules, aircraft ground handling efficiency and aircraft en-route operations. Since there is little an airline can do to control aircraft en-route operations, improving schedule design and aircraft turnaround operations become two feasible approaches to control schedule delays. In certain circumstances, an airline may want to impose specific delay/punctuality control on certain flights. This scenario occurs when these flights carry a higher portion of business passengers or valuable express cargos or these key flights bring significant transfer traffic into a hub airport. As a consequence, specific measures are needed to improve the punctuality control of these flights (they are usually called 'priority flights'). However, two questions still bother airline schedulers: how much schedule time should be allocated to these priority flights to achieve an operational target and secondly, how effective this strategy will be. Since stochastic factors may influence airline operations, it is not appropriate to approach this problem by using analytical methodologies. Instead, stochastic simulation models are used to capture uncertainties in airline operations as well as to provide airline schedulers with answers to those "what-if" questions.

Therefore, a scenario study is carried out by using schedule data of the previous aircraft flying on AAA-BBB route. It is found through data mining of customer background information and field observation that Seg_2 usually carries a high portion of business passengers and express mail & cargo in the early morning. Hence in this scenario study, extra 5 minutes of aircraft turnaround time is allocated for this segment to improve the departure punctuality of Seg_2 at BBB as well as the arrival punctuality at AAA. It is also found in Figure 6 that Seg_3 suffers from long departure delays, so the turnaround time of Seg_3 is increased from 30 minutes to 35 minutes in order to absorb accumulated delays from previous flight segments. The modified schedule is then simulated by ARS model and results are shown in Figure 8 and Figure 9.

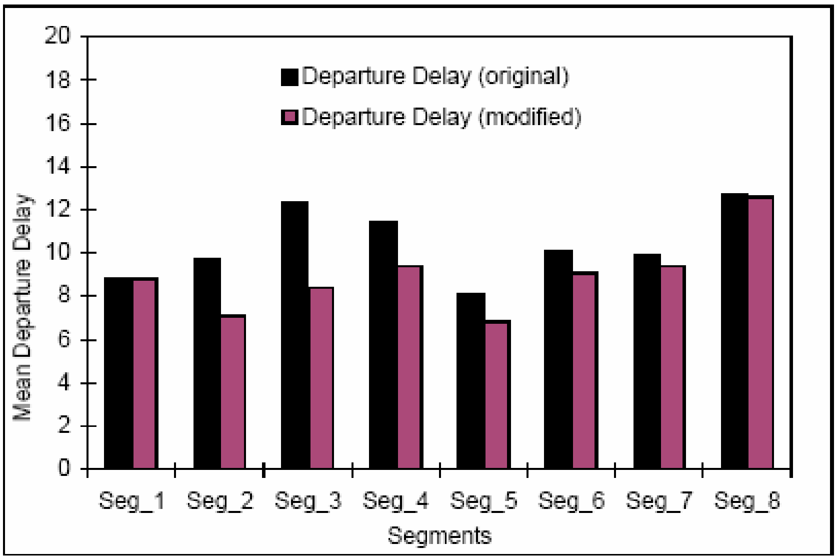


Figure 8. Simulation results from original and modified schedule (Departure delays)

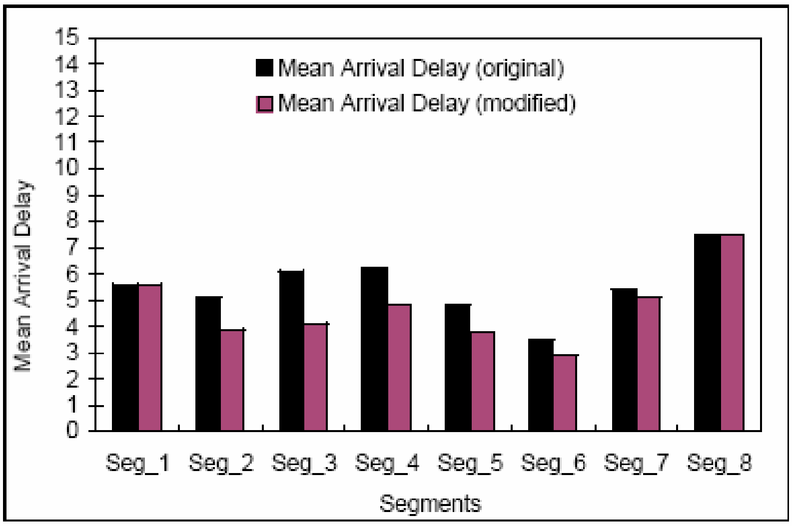


Figure 9. Simulation results from original and modified schedule (Arrival delays)

From above figures, we can find that both departure and arrival delays of the study rotation are improved. The turnaround time increment to the original schedule is only 4% (from 270 minutes to 280 minutes), but the total departure delay is improved by 13% (from 83 minutes to 72 minutes) and meanwhile the arrival delay by 14% (from 44 minutes to 38 minutes). This scenario study has shown how significantly schedule reliability can be controlled if variant schedule times are used at the right place. This case study also reveals the potential of this ARS model as a schedule planning and simulation tool for airline schedulers. ARS model can be calibrated by using historical data to fit most operating scenarios and provides airline schedulers with immediate simulation feedbacks to improve schedule design. This model supplements the schedule planning duty by providing simulation feedbacks as schedule improvement guidance, because these feedbacks are currently not complete during schedule planning process and are usually judged by schedulers' working experience.

5. Discussions

5.1. Punctuality analyses -- the real purposes?

From above, it is seen how operational uncertainties occur and delay flights. Airlines are now much aware of the influence of stochastic factors in airline operations and have started to approach punctuality issues from a stochastic point of view rather than a deterministic one (The Australian Financial Review, 2003). There are two interesting issues worth raising. First, the analyses of schedule punctuality records should be closely examined together with feedback reports from operation managers at airports. It is not unusual to find that generating monthly punctuality figures has become a routine duty for some airlines. These figures merely tell a plain story about how the schedule has performed in the report period instead of why delays are caused in operations. More information about the interaction between punctuality and on-site operations can be dug out from ramp manager reports and delay codes analyses. Airline operations at airports usually involve some local factors such as the working culture of local ground crew, which is believed to be a key issue in maintaining ground operational efficiency at certain airports in Europe.

Secondly, we find that some airline managers do not trust results of delay coding systems. There are mainly two problems relating to the current practice of delay coding systems. One is that there is no suitable measuring standard available to judge which part of aircraft turnaround operations should be responsible for delays because the punctuality of a flight is inter-locked with up and down-stream flights in the rotation schedule. The other problem is about the perception of ground crew towards delay coding systems. It is found difficult to persuade ground crew that the recording of delay causes is not simply to measure work efficiency or to blame someone for delays, but to realise the nature of ground operations and to find a solution to improve flight punctuality. From above case studies, it is not difficult to tell from the quality of delay coding data of an airline how well this delay coding system has been practiced at different airports by the same airline. Air New Zealand has just started an initiative to enforce the delay coding system and meanwhile to educate ground crew about the real meaning of recording delay causes and its true value to the success of airline operations. Air New Zealand believes it would be able to save significant delay costs after the internal campaign, if the punctuality figure could be improved to a certain target level (Lee, Moore, 2003).

5.2. Schedule Planning, Operations Control and Network Reliability

The current schedule planning process usually treats scheduling parameters as deterministic factors and meanwhile, the schedule optimisation process tends to reduce aircraft turn time on the ground in order to increase the utilisation of fleet (Merder, Frank, 2002; Wu, Caves, 2002). By doing this, the flexibility of airline schedules becomes low and consequently flight delays may increase due to low schedule reliability. Airlines usually design schedule buffer time in flight schedules to control aircraft rotations. However, two questions remain: first, where buffer time could be optimally allocated in a flight schedule; secondly, how much time should be designed to “relax” flight schedules in order to achieve punctuality targets.

In previous case studies, we find that Airline P has more frequent delays due to ‘reactionary’ causes. We also find that different flights on different routes reveal different punctuality characteristics and these issues are highly related to certain local ground operation factors as well as schedule planning strategies. As a consequence, schedule buffer time should be placed at those stations at which aircraft turnaround operations suffer from high uncertainties as well as at those stations at which the departure/arrival punctuality is more highly regarded for commercially values (Wu, Caves, 2003a; 2003b).

It is also feasible to optimise a flight schedule by allocating optimal buffer time to each segment. It has been shown in a previous paper by the author (Wu, Caves, 2002) that schedule punctuality can be optimised if stochastic factors are well considered during schedule planning stage. However, this optimisation process needs two prerequisites: (1) deep market research and data mining analyses of passenger behaviour and (2) extensive analyses of historical punctuality and schedule data to pinpoint the weakness of a schedule. Therefore, it is recommended that a system approach to improve the delay coding system should be done in the first place. Massive data mining work should be carried out to explore uncertainty factors found in past operations. Thirdly, schedule simulation should be run on a network-wide scale to improve the reliability of the whole network.

The current environment airlines are operating in is full of uncertainties including system capacity constraints, airport operations, aircraft ground operations and airline operations. These uncertainties may cause deviations to the implementation of airline schedules as well as financial losses. Since airline schedule is a complex network web, delays to a flight segment may cause ripple effects to other flights in the network via inter-locks, e.g. passenger transfer, crew rotation and aircraft rotation. Airline schedules are usually planned at least six months ahead of operations and are highly subject to scheduling constraints such as airport slots, market demands and available resources. Stochasticity occurred in daily airline operations influences the reliability of airline schedules. Since it would too ideal to try to eliminate those uncertainty factors in airline operations, the way to minimise stochastic effects in operations would be to optimise the network reliability of schedules (Wu, 2003a; 2003b). There are two directions to achieve improvement. Stochastic factors should be considered in schedule planning so to bring up the level of schedule flexibility. This can be done by allowing schedule buffer time to be designed for key flights in the network. On the other hand, disruptions to airline operations should be well controlled under operational targets. This will reduce the occurrence of delays and hence improve schedule reliability.

6. Conclusions

Two empirical analyses are carried out to examine the influence of operational uncertainties on schedule punctuality and the implications on punctuality control and schedule planning strategies. It is found that airlines face different uncertainty issues at different airports. Some uncertainties come from schedule planning strategies, e.g. short aircraft turnaround time and some from ground operation disruptions. From punctuality curve analyses, we find that flight punctuality is influenced by the time of a day, operational efficiency of ground crew and more significantly by the design methodology of flight schedules. Simulation models are found specifically helpful in carrying out scenario analyses for schedule planning and optimisation purposes. In a simulation example, it is shown that by increasing 4% schedule time on an example route, flight punctuality could be improved by 14%. This example also demonstrates how an airline is able to control flight punctuality and the overall schedule reliability by considering stochastic factors during schedule planning process.

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