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Optimisation of Aircraft Cost Indices to Reduce Fuel Use

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ABSTRACT

Fuel use in aviation is burdening the industry owing to its expense and worries about carbon dioxide emissions. With limited technological solutions for aircraft, small improvements in fuel efficiency are becoming increasingly important. Cost Index (CI) is a tool which controls the speed of an aircraft and therefore overall fuel use. Although the concept is simple, balancing fuel costs and time-dependent costs it is subject to misuse. This study aims to evaluate how the correct use of CI can affect fuel use and carbon emissions and assess the barriers and measures that are needed in finding the optimal CI value. A range of CI values are modelled for six different aircraft types to assess the difference in flight time and fuel use, before costs are modelled for a B767-300ER. Real aircraft data is used to validate results and provide an insight into the practical flight considerations that are required when using the CI. Results show that although changing CI values may only result in small changes in fuel use of around 1%, when this is applied over a route, an airline and the whole industry the fuel and carbon savings are significant. It is concluded that CI needs to be considered as an important tool and much better understanding of its use is needed along with factors, such as carbon pricing, which will affect its use in the future.

INTRODUCTION

The airline industry is facing increased pressure to reduce its fuel use owing to the combined threats of oil price volatility and ever increasing carbon emissions. Even small decreases in fuel use are important for airlines as the industry faced a fuel bill of $214 billion in 2013, accounting for almost a third of operating expenses, and emissions of 705 million tonnes of carbon (ATAG, 2014). With limited technological solutions to substantially decreasing the industry's dependence on oil, airlines are increasingly reliant on combining small increases in fuel efficiency.

Whilst efforts are continually made to find technological solutions to this problem, there are also simple operational procedures that could have a significant impact on fuel use. One such tool is the Cost Index (CI), which when entered into the flight management system, determines the speed of the aircraft. Slower speeds result in less fuel use and therefore less carbon emissions. However, airlines also have to consider the effect this will have on time-dependent operating costs such as labour and maintenance. A balance must be found between the two sets of costs. From equation [1] the CI calculation appears simple, but in reality there is evidence to suggest that this is not the case.

$$\text{Cost Index}=\frac{\text{Cost of Fuel (\$/kg)}}{\text{Cost of Time (\$/min)}} \qquad [1]$$

It appears that there is sub-optimal use of CI with evidence of a) it is being misused to estimate speeds and/or b) it being miscalculated. In the first instance there are reports that airlines have adjusted CI values to fit schedules, approximate long range cruise (LRC) or have simply adjusted values from other aircraft/manufacturers (Airbus, 1998). In the latter case, miscalculations are common owing to the difficulty in determining the correct time-dependent and fuel costs. As stated by Burrows et al. (2001) CI is "an accounting innovation developed largely by non-accountants" and flight operations can often find it hard to persuade airline financial analysts to determine these marginal operating costs. Additionally, there are a number of factors that will affect the calculation of CI going forward. One of the most important is the introduction of a global carbon price into the industry from 2020, with European airlines already subject to the European Emissions Trading Scheme (EUETS).

The aim of this study is to demonstrate how the use of CI in normal flight operations can affect fuel burn and carbon emissions and explore the barriers that exist in doing this. Additionally factors that will affect the use of CI in the future are also identified. To achieve these aims this study compares a range of CI values for different aircraft models, assesses the costs of a flight and uses real airline data to validate and identify the practical issues of a flight that will affect the CI.

LITERATURE REVIEW

Previous studies on the topic of CI are not numerous with very few studies pertaining to the use of CI as a tool for managing carbon emissions. However, studies have been conducted on the subject for over three decades. Liden (1985) sets out some of the principles of the relationship between CI and flight parameters, such as speed, flight time and fuel burn. Using simulations of DC-10 aircraft, the aim was to demonstrate how the optimum CI can be calculated, but also how the speed could be adjusted to achieve a desired flight time. This methodology is now outdated as more powerful computer programmes have become available to calculate optimum CI values, but the relationships between flight parameters and CI are still important.

Another early study on CI was that of Dejonge and Syblon (1984) which explored the use of CI in the American Airlines fleet. It is described how in 1979 savings in fuel of 2.1% were associated with the use of CI. This was when the service was point-to-point, but the paper goes on to explain how this changed with deregulation and the creation of hub-and-spoke operations. At American Airlines, as with many other airlines, the

standard was for 65% of flights to arrive within five minutes of schedule and 85% of departures operated within 10 minutes of schedule. This highlights one of the issues in using CI with network schedules needing to be met, an issue that has increased in importance since with increasing demand for air travel.
Cook et al. (2009) have produced the most extensive work on CI costs with the aim of developing a dynamic CI in the case of delay. The study highlights the difficulty in airlines quantifying the time-dependent costs of a flight stating “many airlines will readily concede that the way delay recovery decisions are made can be arbitrary, or based on crude rules of thumb”. The study identifies the key elements that need to be considered in order to create a successful dynamic CI. These include air traffic control (ATC) and air traffic management (ATM) issues; costs to the airlines; and aircraft performance, and operational capability of the aircraft to adapt its speed. The last factor concerns environmental impact. The inclusion of this is an acknowledgement that the political position over emissions is uncertain, therefore adopting a flexible framework is necessary. The two main objectives are to ensure the model of CI is still useful if emissions-related charges are introduced and to allow airlines to take emissions into account in their decision making process when responding to delay.

Looking at CI from a cost management perspective, Burrows et al. (2001) suggest that airlines are failing to exploit CI’s full economic potential and identify the causes and costs arising from sub-optimal behaviour. The study identifies that CI should be aircraft, route, airline, stage and direction specific; that there is evidence that airlines are making basic errors or questionable assumptions in their use of CI; and that there is an apparent widespread use of average CI values for a range of routes. The effects of these errors may include misidentifying the ECON speed, average CIs underestimating wide divergence in fuel prices on different sectors, failure to revise CI values when fuel or other costs change substantially and a general misunderstanding of flight costs.

Whilst Burrows et al. (2001) and Cook et al. (2009) provide valuable insights into the how CI values should be calculated and highlight areas where there may be miscalculation, there is still no indication of the magnitude of errors and the effect this can have on fuel use and carbon emissions. The early studies, particularly Liden (1985) do this to some extent but these findings are now outdated and do not reflect the current situation of increasing fuel costs, introduction of carbon prices and other factors, such as increased congestion and complex scheduling. The aims of this study are designed to fill these gaps where possible, as well as provide insight into where future research is needed.

METHODOLOGY

Comparison of Aircraft Models

For a comparison of the CI ranges for different aircraft models the aircraft analytical tool Piano-X was used. Six models were available for comparison: A300-600R, A340-600, A380-800, B767-300ER, B777-300ER and the B787-8. For direct comparison the same route was used for each aircraft over a distance of 3000 NM, chosen to represent a long haul flight, taking into account the shortest maximum range of 4500NM for the A300-600R. The standard settings for Piano-X for each aircraft type were used with no restriction on available flight levels. A load factor of 80% was used assuming a 3-class seating configuration, with no cargo on board.

Flight outputs were generated for economy speed, LRC and Max speed. The economy setting represents the maximum range cruise (MRC) where aircraft fly with minimum fuel use. Max speed represents the physical speed limits of the aircraft, although in theory CI values can be higher than this, whilst the LRC represents a speed at which a 1% fuel penalty is accepted over MRC in exchange for a faster flight time. The speed at which a balance in costs is found is called the ECON speed. Mach numbers were chosen at suitable intervals between the MRC and the Max speed to give a comprehensive range of flight speeds. For each Mach number the block fuel and block time were taken from the Piano-X output. Using MRC as CI=0, the time saving and extra fuel for each increase in speed above this was calculated and the CI was found by dividing extra fuel by the time saving. To allow for comparisons of flight time against fuel burn for different aircraft fuel per passenger was calculated.

B767-300ER Costs

To demonstrate the role of CI in finding the ECON speed, costs calculated by the University of Westminster (2008a; 2008b) for Eurocontrol were utilised. The B767-300ER was used as it was the only aircraft model available in Piano-X that also had available cost information. The two major time dependent costs, labour and maintenance, were used for the three scenarios set out in the University of Westminster study. The base scenario for labour is representative of an 85% load factor, no additional flight crew and five additional cabin crew members, in addition to mandated numbers, with overtime payment and 30% on costs; the low scenario assumes that with careful management of crew working hours it is possible that no extra payment is needed per marginal minute; and the high scenario represents a situation where there is a 75% load factor, one relief captain, seven additional cabin crew members and overtime payment with 40% on costs. These costs are representative of 2008 but in comparison to fuel costs they are not expected to have changed significantly.

To provide an up to date representation of the balance of time-dependent costs and fuel costs the average fuel price of 2013 was used of $142/bbl. To demonstrate the impact of jet fuel prices the peak fuel price from 2008 of $180/bbl was used (Air Transport Department Cranfield University, 2010). In addition, to provide an indication of how fuel prices may change in the future, scenarios for 2020 and 2030 were used (DECC, 2013a) along with a future carbon price (DECC, 2013b). The base (central) scenario for fuel prices is based on DECC's long term forecast model with central parameters, the low scenario represents a situation where unconventional oil will remains economic and for the high scenario, the model is adjusted to represent zero global supply growth to the period 2030. As these figures are only for crude oil an addition of 25% was added to account for the crack spread for jet fuel. For carbon prices the base (central) scenario is based on a market based approach involving averaging daily settlement prices of EUA futures contracts; the low scenario represents a pessimistic outlook assuming continued oversupply and lack of demand for allowances for the period to 2020; and the high scenario represents a situation where there is higher economic growth, low prices of coal relative to gas and tighter EUETS caps. All these costs are presented in Table 1.

TABLE 1 Costs for B767-300ER [Data Source: University Of Westminster (2008a, 2008b); DECC (2013a, 2013b)].

	Time-Dependent Costs ($/min)		Jet Fuel Cost ($/kg)				Carbon Price ($/kg)	
	Maintenance	**Labour**	**2008[1]**	**2013[2]**	**2020**	**2030**	**2020**	**2030**
Low	6.6	0	1.39	1.10	0.83	0.72	0.00	0.06
Base	6.9	18.3	1.39	1.10	1.16	1.30	0.01	0.11
High	9.2	49.5	1.39	1.10	1.45	1.88	0.04	0.17

[1] Peak jet fuel cost in 2008, [2] Average jet fuel cost for 2013

Real Aircraft Data

Data from a B777-300ER flight was provided by a major international airline with one year of data (2013) for an overnight flight of just over 5000NM. The aircraft uses a CI of 40 for this flight. The data was initially used to look for the effect of factors such as ISA deviation, altitude and wind conditions on flight time and fuel consumption. Taking these factors into account the data was then used validate the methodology used in section 0.

It was not possible to carry out analysis on each flight individually; therefore flights were divided into six different groups based on distance (either 5553NM or 5619NM) and maximum flight level (FL320 to FL380) with their averages used. Distance, max flight level and average passenger number (based on average weight) were inputted into Piano-X. The same method was then used to calculate the CI as in section 0. The block fuel and time was found for a range of Mach numbers, but also ensured that the Mach number for CI=40 was found. This allowed comparison with the data from Piano-X, which was adjusted to account for the wind speeds seen in the real flights. Carbon emissions were calculated for the different CI values using the standard conversion of 1.357kgCO_2/kg-fuel.

The real aircraft data also allowed for investigation of the effect that changing CI would have on the scheduling of the aircraft. The real aircraft data provided flight times and, with the scheduled time of departure and arrival known, the amount of buffer time could be calculated. In addition Flight Aware (2014) was used to examine the actual departure and arrival times of this particular flight over a four month period.

RESULTS

Comparison of Aircraft

It is evident from Table 2 that there are significant differences between all aircraft types evaluated in this study. When the fuel saving between MRC and Max speed is considered then reductions of up to 12.3% could be achieved for the A340-600. However, airlines generally fly at close to LRC in normal flight operations. The difference between MRC and LRC is much smaller at between 0.6% and 1%. But these changes are still important to an industry with profit margins of just 0.1% over the last 40 years (IATA, 2011). It is also notable that the range of CI values varies greatly for the different models, from a maximum of 28 for the A300-600R to 320 for the A380-800.

The range of CI values can be further observed in Figure 1. This relationship is as expected, with time savings coming at the expense of extra fuel use at higher CI values. It is also interesting to note that if a negative CI was to be chosen this would result in a slower time, but an increase in fuel. This was also found by Liden (1985) but it is still unclear as to why this happens. The smaller aircraft, B767-300ER and A300-600R, have smaller ranges of CI over this distance before maximum speed is reached and show much flatter curves, meaning that a decrease in flight time only results in a small change in fuel use. The larger aircraft also demonstrate this relationship at low CI values, but as their range of CI values increases, large fuel penalties become evident for small changes in time, particularly for speeds higher than LRC.

TABLE 2 The Effect on Block Fuel and Block Time Between MRC And LRC/Max Speed

		% Difference MRC to Max	**% Difference MRC to LRC**	**CI LRC**	**CI Max**
Airbus A300-600R	Block Fuel	1.12	0.6	20	20
	Block Time	3.0	2.3		
Airbus A340-600	Block Fuel	12.3	1.2	80	80
	Block Time	4.9	1.7		
Airbus A380-800	Block Fuel	6.9	1.0	103	103
	Block Time	4.0	1.7		
Boeing B767-300ER	Block Fuel	3.4	0.5	14	14
	Block Time	5.1	2.3		
Boeing B777-300ER	Block Fuel	3.4	0.7	42	42
	Block Time	3.0	1.7		
Boeing B787-8	Block Fuel	4.5	0.6	24	78
	Block Time	3.7	0.7		

The general relationships found in this study are the same as those found in earlier studies. Most notably Liden (1985) describes how variations in CI near the optimum value have a negligible effect on total costs with a similar result found here, that at smaller CI values where the optimum usually lies there is a much smaller change in fuel use than at higher CI values and therefore the effect on total cost is less.

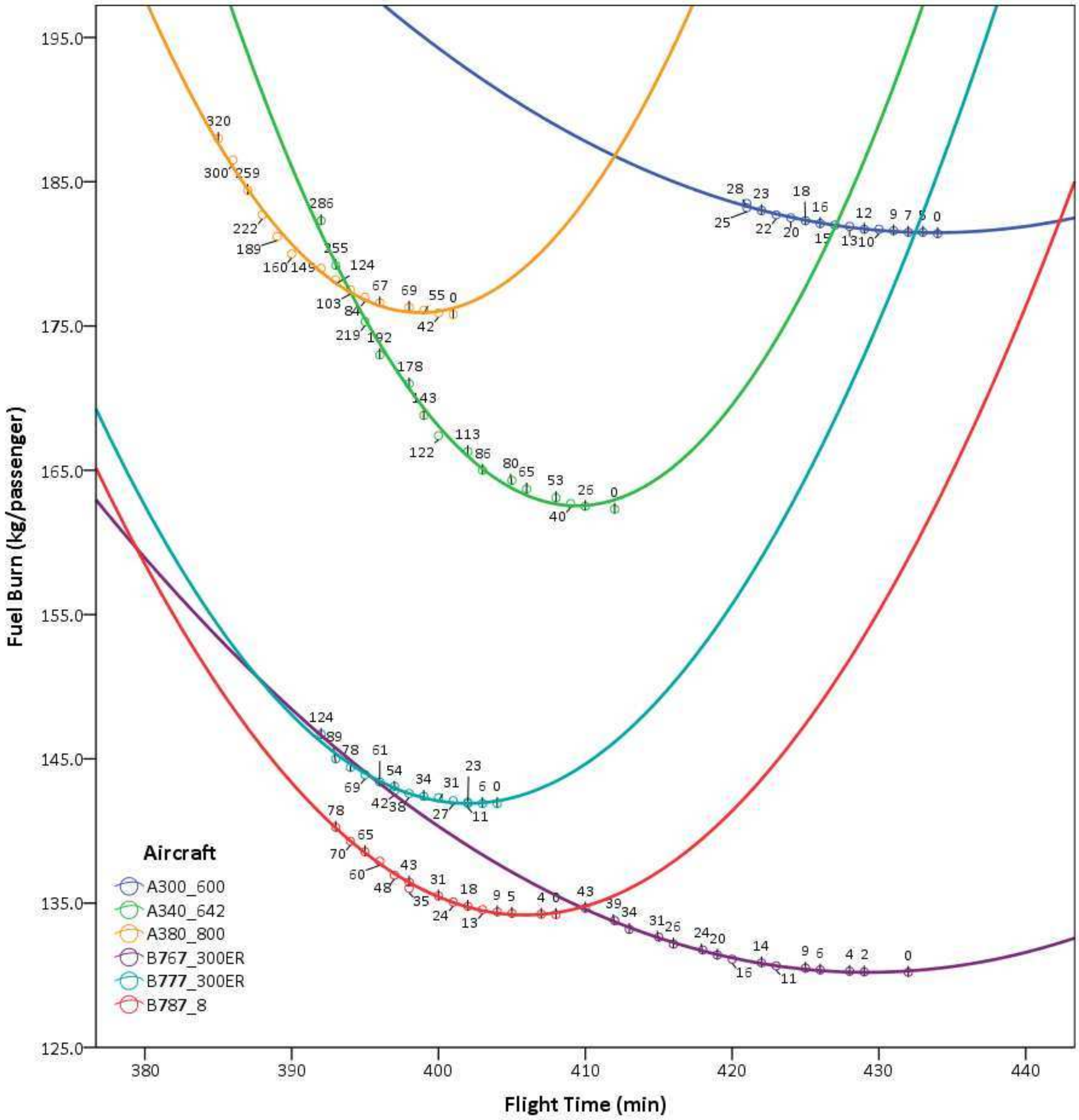

FIGURE 1 Relationship between fuel burn per passenger and flight time with Cost Index values shown for six aircraft models

Comparing the different aircraft models in this way shows that there is considerable difference overall in terms of both fuel use and flight time. For this particular flight distance, the B787-8 demonstrates the best potential, with both low fuel use and low flight time, compared with the other aircraft. The B767-300ER shows the best results in terms of fuel consumption but with a considerable penalty in flight time. The B777-300ER performs well, with a slightly higher fuel use per passenger but with the fastest flight times of the Boeing aircraft.

The Airbus models perform less well over this distance. Clearly the A300-600R is not suitable for this route length with high fuel use and flight times. The A380-800 on the other hand offers the fastest flight times of any of the aircraft models, but this comes at the expense of high fuel use. It is stressed that this is only for the given distance of 3000NM but does highlight the importance of optimisation of aircraft and CI for different routes. For example, the A300-600R, although technically capable of 3000NM range, is designed for use of shorter medium haul flights. Likewise the A380-800 is a very large aircraft and therefore is better suited to longer haul flights. Consequently, individual analysis is needed for different flight routes to discover the best aircraft type for efficiency.

B767-300ER Costs

Figure 2 shows that when the CI increases this causes fuel costs to also rise whilst the time-dependent costs decrease as expected. The optimum CI occurs at the point at which these costs meet. When considering the 2013 fuel cost this happens at around CI=2 for the low time-cost scenario, CI=6 for the base time-cost scenario and CI=9 for the high time-cost scenario. For the 2008 peak fuel cost the CI still equals two for the low time-cost scenario but comes down by one for the base and high time-cost scenarios. In terms of future fuel prices, the base case for 2020 will not have a significant impact on CI, even with the addition of the base carbon price for 2020. Similarly the base case for 2030 does not even reach the 2008 peak fuel price and its effect is not significant on the CI. However, when carbon prices are added for 2030 more significant changes do occur. For the base case this brings the CI close to one with low time-costs, down to around CI=4.5 from CI=6 for the base cost scenario and to CI=8 in the high cost scenario. The biggest effect on CI if time-costs hold at their current levels would be from the high carbon price and fuel cost scenario with the CI equalling around one, three and six for the low, base and high time-costs respectively. This represents a lowering of carbon emissions of 0.1% equalling 8849 kg per flight. On the other end of the scale is the low fuel cost scenario with no carbon costs attached. This is an unlikely scenario but has been included to show the large variability in CI values that could be seen in the future.

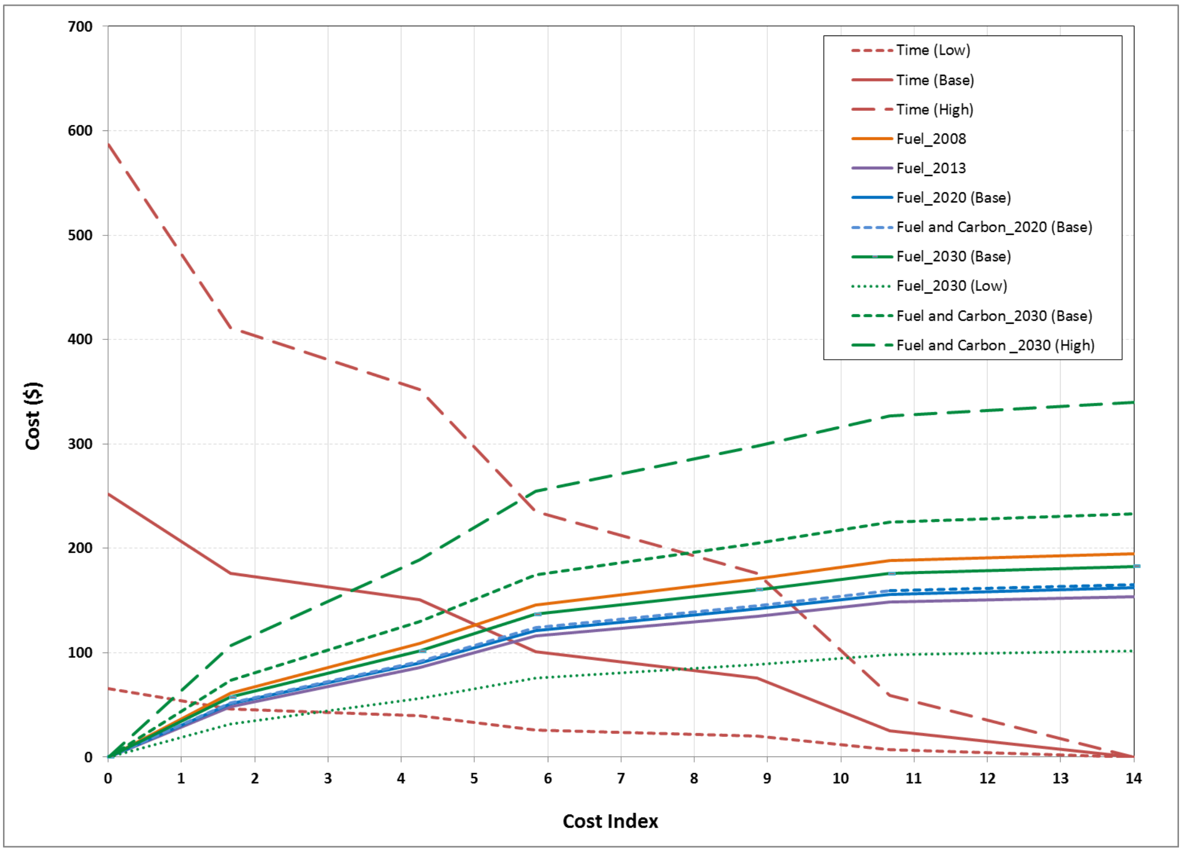

FIGURE 2 Cost of fuel and cost of time between MRC And LRC Cost Index values for the B767-300ER

Real Aircraft Data

When fuel burn for the real data is compared with that of Piano-X the average difference between fuel burn for the two is around 6000kg. This difference can be explained by variations in flight conditions between the ideal and the real cases. The biggest impact comes from wind speed, with an average headwind on this route of 26kt. Out of the flight parameters available wind speed showed the strongest significant correlation with fuel burn. In theory the flight management computer should adjust the CI value to account for wind speed so a balance of costs can still be found. However, the CI cannot compensate for this change in speed due to a headwind completely and therefore, the overall flight time will also be increased, with a strong correlation being found here.

When the Piano-X fuel use is adjusted to account for this headwind in most cases this reduces the difference between the real and ideal flights to just a few hundred kilograms of fuel. However, in two cases, large gaps in fuel use still remain between the two. This can be explained by the maximum allowable flight level which is constrained to FL320 and FL340 in these two cases. A significant correlation occurs between flight level and fuel burn because air is less dense at higher flight levels and so there is less drag on the aircraft. Similarly ISA deviation is seen to have an effect on fuel use as higher air temperature results in lower air pressure and consequently less drag.

The real aircraft data also provides an opportunity to look at whether there is buffer time in the schedule enough to accommodate a change in CI. From Figure 3a it is apparent that all flights leave late from the origin airport. The scheduled time for departure is 11.55PM local time but the majority of flights leave between 12.15AM and 12.35AM. Figure 3b shows the majority of flights also arrive early at the destination airport. With a scheduled time of 05.40AM local time most flights arrive between 05.00AM and 05.20AM. There are a small number of flights that do arrive late but these represent some very late departures from the origin airport of over 40 minutes. For this particular flight there is more than enough time in the schedule to accommodate the extra 12 minutes needed to move from CI=40 to CI=0 in order to save fuel under normal flight conditions.

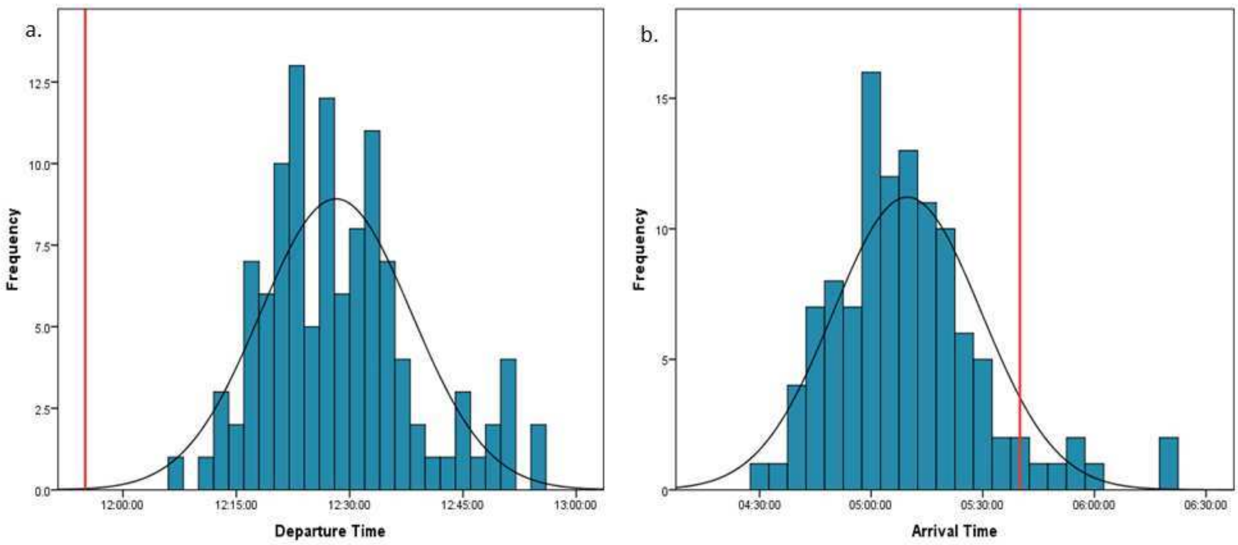

FIGURE 3: A. Departure and B. Arrival times for real data flight route over four months with red line indicating the scheduled time [Data Source: Flight Aware (2014)]

Overall, this flight could experience fuel savings of between 0.03% and 0.71% resulting in carbon savings of up to 2090kg per flight. In monetary terms this is a saving in fuel costs of between $32 and $655 per flight. This may seem small but considering flights on a yearly basis with eight flights per day on this route, a saving of $500,000 could be achieved. If the whole fleet of B777-300ER aircraft for the airline in question is considered, covering a distance of 141,336NM on a daily basis, then a saving of $1.4 million could be seen along with a carbon saving of 4873 tonnes.

DISCUSSION

The results of this study indicate that the CI is an important tool for determining the fuel burn of a flight and consequently the contribution of that flight to carbon emissions. Although percentage changes in fuel use and carbon emissions may appear small, for an airline that can easily spend hundreds of thousands of dollars on jet fuel every day and an industry that emitted 705 million tonnes of CO_2 in 2013 (ATAG, 2014), these are significant savings.

However, the first hurdle in making sure the fuel is used efficiently, taking in account other time-dependent costs, is to make sure that the right CI is being calculated. Significant differences were found in CI between different aircraft types. Although they all showed the same general relationships of fuel use and time, there were big differences in the overall fuel use. This highlights the fact that even before CI is chosen, aircraft selection for individual routes is vital to fuel efficient flights as different aircraft are designed to fly different distances optimally. The comparison of aircraft also demonstrated that the relationship between CI and fuel use is not linear and the biggest reductions in fuel use are experienced when moving from high CI values, particularly above LRC. However, even at lower CI values where the saving in fuel may be a lot less, changes in CI are still important with Burrows et al. (2001) stating that savings of even $150 per sector by an airline, which serves 20 similar sectors daily, would produce an annual saving of around $1.1 million. Therefore, continually ensuring that CI values are accurate can be seen as a contribution to a kaizen type cost reduction process where continual savings in costs are being made.

The biggest error in calculating CI values undoubtedly comes from the miscalculation of operating costs. For analysis of the B767-300ER costs in this paper, values from Cook et al. (2009) were used as these are the most comprehensive figures available, but it is stressed that there are still a large number of assumptions associated with them. This being said, the example given of the cost balance for the B767-300ER provides a demonstration of the effect of varying fuel prices, which will be a critical factor in the calculation of CI going forward. It is clear that small fuel price changes do not have a significant effect on the CI up to 2020. However, substantial changes do occur with 2030 jet fuel price projections when a carbon price is added in. If the carbon price is to have any effect on the day-to-day operations of aircraft it is important that the price is set sufficiently high to move to lower CI values. Analysis of balance of costs, as performed in this study, should be a central part of determining suitable price levels. For the B767-300ER there is only a small range of CI values over 3000NM, therefore for other aircraft models with a wider range of CI values available savings in carbon emissions are likely to be higher.

Whilst fuel costs can be very variable and therefore require CI values to be updated regularly, time-dependent costs will generally be more stable and the airline has more control over them. But as already stressed the difficulty is in knowing what these costs are in the first place. No overall solution can be provided to the industry due to each airline having different cost structures.
Labour costs vary owing to the number of different expense and salary packages that are available with three key drivers of costs as follows:

- The country of operation – different countries have different salary expectations.

- The type of operation – in general national carriers pay more than low cost airlines, as well as providing more classes of travel, requiring more cabin crew on board.
- The size of the aircraft – salary for flight crew increases with aircraft size and with more seats and class options, more cabin crew are required for larger aircraft.

Even in the same airline and on the same aircraft there can be a large range of salaries for the same job category depending on experience. For example, on a B747-400, the range of salaries is from 110,000 euros to 205,000 euros for a captain (University of Westminster, 2008a). Additionally flight crew costs become complicated above certain distances owing to the requirement of a relief captain to be on-board and the number of rest hours required between flights being proportional to the number of block flight hours (Swan and Adler, 2006; Burrows et al., 2001). This suggests that CI needs to be not only route and aircraft specific but also flight specific.

Although it may appear that airlines have more control over labour costs than costs such as fuel, this may not always be the case. Since deregulation, airlines have tried to reduce labour costs through increased productivity, but this has only been successful up until a point as regulation requires a certain number of crew on-board the aircraft and mandates working hour restrictions. The biggest changes in labour costs are likely to result from these changes in regulation, something that has been recently seen in Europe with the European Parliament implemented new legislation as of 2013 regarding aircrew fatigue. Maximum flight duty time has been decreased from 11 hours 45 minutes to 11 hours of night flying for pilots with a reduction in the maximum number of flying hours in 12 consecutive months from 1,300 to 1,000 (European Commission, 2013). Changes such as these will require airlines to adjust their CI as they may have significant effects on labour costs.

Maintenance is the other key time-dependent cost which can be very difficult to calculate. Regular maintenance consists of four different line checks that vary from short at gate checks to a month long process of total disassembly of the aircraft. Intervals between these checks depend on either flight hours or number of months between checks, therefore increasing flight time means more checks of the aircraft. Many airlines now outsource their maintenance through power-by-the-hour contracts or cost-per-flying-hour contracts with financial penalties for exceeding the agreed contract hours (University of Westminster, 2008b). Problems arise with calculating maintenance costs as there are so many joint costs involved that it can be hard to separate those that are driven by flight cycles compared to those that are driven by flight hours (Burrows et al., 2001; Doganis, 2002). Even when maintenance costs can be accurately calculated, CI values must still be reviewed at suitable intervals as maintenance costs will change with the age of the aircraft (University of Westminster, 2008b).

One of the key elements in changing a flight's CI is whether the schedule can accommodate this change. For the real flight used in this study there was more than sufficient buffer time to change the CI value. However, this may not always be the case and therefore if airlines are to fly efficiently this may require a change in schedule, with the knock on effects this may have on costs needing to be taken into account. The realities of an actual flight must also be considered. As highlighted from the real aircraft data results, wind is a particularly important factor to consider. Although the flight management system does take wind speed into account when using CI, this may have adverse effects on the schedule. The flight level used is also very important and can have a significant effect on flight time and fuel burn. A CI may be optimum at one flight level and not another and can be changed by ATC, therefore airlines need to be aware of these changes to implement optimum CIs more flexibly.

Another area where airlines may have little control is over holding at their destination airport implemented by ATC. There is little point in flying with optimal CI values when holding may expend more fuel and increase overall flight time. A future solution would be to integrate ATC and airlines more effectively with the use of 4-D trajectories allowing for a timed arrival. In practice this works by ATC initiating a trajectory negotiation via datalink when a flight is around 40 minutes away from its destination. The 3-D route is agreed by the aircraft and ATC and then the aircraft's flight management system finds an estimated time of arrival and ATC will confirm a controlled arrival time. Research has shown that this is operationally and technically feasible but it will require collaboration from key stakeholders to become a reality (Mutuel and Neri, 2013).

Whilst there are still many issues relevant to CI today, it is also important to consider that a number of factors will affect its use in the future. As already mentioned carbon pricing is an upcoming issue which will need to be factored into the fuel side of the CI equation. There has been a significant push for carbon trading to be introduced into the aviation industry for a number of years but the biggest move towards this came in 2012 when aviation was included in the EUETS. This was originally set to include all aircraft arriving and departing in Europe. However, after strong resistance form some international airlines the European Commission used this as an opportunity to encourage a global trading agreement to be decided upon by ICAO. The European Commission "stopped the clock" for flights arriving and departing from outside of Europe until a global agreement was reached at the ICAO Assembly in 2013. The result was that ICAO agreed that a global market based mechanism would be decided upon by 2016, ready for implementation from 2020. Therefore carbon pricing seems an inevitable part of the aviation industry in the future.

There are also a number of other factors which will play their part, such as changes in aircraft technology that reduce fuel use and maintenance costs, changes in the size of aircraft, congestion issues and airport expansion, political and technological impacts on oil prices and pricing of airspace affecting certain routes. Additionally, as well as aviation impacting on climate change, climate change may also impact on aviation by changing the jet stream and potentially increasing severe weather events. Therefore, it is not only essential that CI is further researched and optimised at present, but also further research is needed into the changes in the future that may have an effect on the industry.

CONCLUSION

This study has demonstrated that CI is an important tool for controlling fuel use on a flight-to-flight basis. Even with small improvements in fuel use of around 1% the industry could save around $2 billion in fuel costs and seven million tonnes of carbon emissions annually. At present it is unclear how many airlines may be using the wrong CI, but the evidence suggests that misuse is widespread. The key barrier to using CI successfully is the calculation of time-dependent costs and this is unlikely to be resolved until flight operations and financial departments of airlines cooperate on this issue. Fuel use will be a key factor in the future in determining CI values but reliance of this alone is unlikely to reduce CI values and therefore carbon emissions. To do this a sufficient carbon price will be needed to encourage airlines to move to lower CI values and it will be important for policy makers to take this into account when considering the use of carbon pricing.

Looking forward it will also be important to consider the whole system. Even though airlines can effectively decide on their own CI values, they are still subject to changing ATC constraints which may have an adverse effect on fuel use. Better coordination is needed between these two stakeholders to reduce the likelihood of this and a move towards 4-D trajectories may be an key part of this. There will also need to be further research on how developments within the industry, such as technological changes, policies regarding congestion and environment effects will impact on the use of CI in the future and whether carbon emissions are likely to increase or decrease as a result. In general there needs to be a better understanding of the use of CI and for it to be seen as dynamic tool for ensuring each flight is as efficient as possible.

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